PRODUCTION PROTOCOL FOR ORGANIC TOMATO

(*Lycopersicon esculentum* Mill.)

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DECLARATION

I hereby declare that this thesis entitled '**Production protocol for organic tomato (*Lycopersicon esculentum* Mill.)**' is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title, of any other university or society.

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CERTIFICATE

Certified that this thesis entitled **'Production protocol for organic tomato (*Lycopersicon esculentum* Mill.)'** is a record of research work done independently by Sri. Abhijith Kumar, V.P. (2008-11-108) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

@	-	At the rate of
^0B	-	Degree Brix
%	-	Per cent
^0C	-	Degree Celsius
BCR	-	Benefit-cost ratio
Ca	-	Calcium
CD	-	Critical difference
cm	-	Centimeter
CO_2	-	Carbon dioxide
DAP	-	Days after planting
DAS	-	Days after sowing
DAT	-	Days after transplanting
DMP	-	Dry matter production
^0E	-	East
et al.	-	And others
Fe	-	Iron
Fig	-	Figure
FRBD	-	Factorial Randomized Block Design
FS	-	Flowering stage
FYM	-	Farmyard manure
g	-	Gram
HS	-	Harvesting stage
ha^{-1}	-	Per hectare
IAA	-	Indole Acetic Acid
i.e	-	That is
KAU	-	Kerala Agricultural University
kg	-	Kilogram
kg ha^{-1}	-	Kilogram per hectare
K_2O	-	Potassium oxide
LAI	-	Leaf Area Index

m	-	Metre
mg	-	Milligram
Mg	-	Magnesium
MAP	-	Months after planting
MOP	-	Muriate of potash
N	-	Nitrogen
^0N	-	North
NAA	-	Naphthalein Acetic Acid
NLPI	-	Number of leaves preceding inflorescence
NO_3	-	Nitrate
NPK	-	Nitrogen-phosphorus-potassium
NPKS	-	Nitrogen-phosphorus-potassium-sulphur
NS	-	Non significant
pH	-	Power of hydrogen
POP	-	Package of practices
P_2O_5	-	Phosphorus pentoxide
PPFD	-	Photosynthetic Photon Flux Density
q ha^{-1}	-	Quintals per hectare
Rs	-	Rupees
SE	-	Standard Error
t ha^{-1}	-	Tonnes per hectare
TLCV	-	Tomato Leaf Curl Virus
TYLCV	-	Tomato Yellow Leaf Curl Virus
TSS	-	Total Soluble Solids
viz.	-	Namely
WAT	-	Weeks after transplanting
w/w	-	Weight by weight

INTRODUCTION

1. INTRODUCTION

Tomato (*Lycopersicon esculentum* syn. *Solanum lycopersicum*) is world's largest vegetable crop after potato and sweet potato, but it tops the list of canned vegetables. It is known as 'protective food' both because of its special nutritive value and also because of its widespread production. Tomato is one of the most important vegetable crops cultivated for its fleshy fruits. The inhabitants of Central and South America have used tomatoes as food since prehistoric times. It has originated in the Peruvian and Mexican regions. It was introduced into Europe by the Spanish explorers in the early sixteenth century. European migrants later on introduced it to the U. S. A. and Canada. The Portuguese perhaps introduced it into India though there is no definite record of when and how it came to India. Tomato is said to be the native of Tropical America. The word tomato, not used until 1695 is said to be derived from the Aztec 'Xitomate' 'Sitotomate' (Prasad Babu et al., 2010). From Tropical America it spread to other parts of the world in the 16th century and it became popular in India within the last six decades.

Tomato is considered as an important commercial and dietary vegetable crop. As it is a short duration crop and gives high yield, it is important from economic point of view. Tomato fruit is a rich source of minerals, vitamins, organic acids, essential amino acids and dietary fibres. Tomatoes are an excellent source of ascorbic acid, a nutrient known for its antioxidant action. High intake of ascorbic acid may prevent atherosclerosis, diabetes, colon cancer and asthma (Shweta and Deepika, 2007). It is a rich source of Vitamin A also. The fibre in tomato lowers the cholesterol and also helps in removing carcinogenic compounds from the colon. From the health point of view, tomato fruit can be considered as a mini doctor as it can decelerate heart diseases via lycopene pigments and probability of cancers due to the presence of antioxidants including lycopene and bioflavanoids.

Tomato is a warm-season crop. The plants cannot withstand frost and high humidity. Also, light intensity affects pigmentation, fruit colour and fruit set. The plant is highly affected by adverse climatic conditions. It requires different climatic range for seed germination, seedling growth, flower and fruit set and fruit quality. High temperatures accompanied by low humidity and dry winds frequently damage floral parts and there is no fruit-set. The crop does well under an average monthly temperature of 21^0C to 23^0C but commercially it may be grown at temperatures ranging from 18^0C to 27^0C. The mean temperatures below 16^0C and above 27^0C are not desirable. The plant doesn't withstand frost, it requires low to medium rainfall and does well under average monthly temperature of 21^0C to 23^0C.Temperature and light intensity affect the fruit-set, pigmentation and nutritive value of the fruit. Both high and low temperatures interfere with the setting of fruit. The tomato withstands drought fairly well but fruits are subject to blossom end rot and cracks if moisture supply follows drought. It cannot be grown successfully in regions of higher rainfall.

Tomato grows on practically all soils from light sandy to heavy clay. Light soils are good for an early crop, while clay loam and silt-loam soils are well suited for heavy yields. The best soil for tomato is rich loam with a little sand in the upper layer and a good clay in the sub-soil. Good texture of the soil is of primary importance.

Today, the burgeoning population pressure has forced many countries to use chemicals and fertilizers to increase the farm productivity for meeting their food requirements. But the prolonged and over usage of chemicals has however resulted in human and soil health hazards and has adversely affected the sustainability of agricultural production systems. In India too, the green revolution laid emphasis on hybrid varieties and increased yield with high inputs; it totally neglected the low input agricultural practices. Long term field experiments have made clear the negative impact of continuous use of chemicals on soil health (Yadav, 2003). Hence, there is a paramount need to take meaningful steps towards the establishment of sustainable agriculture not only to ensure food and environmental safety but also to minimize the application of energy intensive inputs. It is in this context, the concept of organic farming gains importance.

Today micronutrient deficiency is a major problem in the agricultural sector especially for vegetable production which can be penalized via the promotion of organic agriculture. Organic farming is a reliable way to increase nutrients i.e, micronutrients, decrease nitrate levels and also reduce exposure to pesticides through foods. Although many people in the third world do not have enough food even once a day, those in the developed countries are concerned about the quality of food. Increasing attention has been focused on chemical residues of food because of their long-term effects on human as well as environmental health.

In this context this study is taken up with the objective of developing production protocol for organic tomato cultivation involving organic nutrition, plant population and plant protection. The study also aims to compare the variation in productivity between organic and conventional systems of cultivation along with the economics of organic production and to assess the residual effect of organic nutrition on the succeeding crop.

REVIEW OF LITERATURE

2. REVIEW OF LITERATURE

Tomato is one of the most important vegetable crops cultivated for its fleshy fruits. Since vegetables are consumed fresh or only partially cooked, they should be devoid of residual effect of chemicals. Organic farming is essential for producing quality vegetables devoid of toxic residues. This chapter pertains to the review of research results of tomato as influenced by different sources and doses of organic manures and planting spacing. In Kerala organic production of tomato lack sufficient research attention and published work is rather limiting. However, available literature on this crop is cited. Wherever sufficient information is not available in tomato, citations on other related crops are included.

2.1. Characteristic features of organic sources used

Organic manures contain most of the nutrient elements needed for plant growth. On addition to soil, they improve soil aeration, permeability, water and nutrient holding capacity and biological properties of soil. It also acts as a buffer and keeps the soil pH within the desired range (Banerjee, 1998).

Farmyard manure (FYM) is the readily available and most common organic manure in India. It consists of a mixture of animal shed wastes containing dung, urine and some straw (Gaur, 1994).

Vermicompost is a potential source of readily available nutrients, growth enhancing substances and a number of beneficial microorganisms like nitrogen fixing, phosphorus solubilising and cellulose decomposing organisms. Vermicompost can substitute or complement chemical fertilizer. It also contains various aminoacids and minerals which humidified the organic matter and surrounding soil and act as a biofertilizer for plant (Shanbhag, 1999).

Enriched vermicompost is an organic manure that enriches the compost with nitrogen and phosphorous making it available to plants in required form. The fertility of the soil is also maintained due to the action of microbes.

Simultaneously it also protects the crop from pests and diseases. Enriched vermicompost with high manurial value for organic farming can be prepared by adding biotic and abiotic agents. Nutrients in vermicompost depend upon type of raw materials used and methodology in preparing vermicompost. It also contains growth regulators like cytokinins, gibberellins, NAA and other beneficial microorganisms. However, the dosage of enriched vermicompost can be reduced by considering its application rate in proportion of micronutrients added to it, as per the soil report and crop selected for cultivation.

2.2. Effect of nutrient sources on plant growth characters

2.2.1. Organic nutrient source

Vadiraj et al. (1992) found that vermicompost application resulted in increased plant height and leaf area of turmeric over the control. Raj (1999) reported that in bhindi growth characters like plant height, LAI and dry matter production was higher in organic manure treated plots. According to Sailajakumari (1999) application of enriched vermicompost (vermicompost with rock phosphate) increased the plant height, number of branches, nodule number and yield in cowpea. According to Arunkumar (2000) FYM and vermicompost application was superior to Package of Practices Recommendations 'Crops' (POP) 1996 with respect to yield and growth characters.

Zaller (2007) reported that biomass allocation towards roots tended to be higher with higher proportions of vermicompost in the substrate for two varieties of tomato indicating that vermicompost stimulated root growth. Not only nutrient contents of vermicompost affect plant growth but also other indirect effects via inhibition of plant pathogen infection and effect on the rhizosphere microflora.

Federico et al. (2007) reported that addition of vermicompost increased the height of tomato plants significantly but had no significant effects upon the number of leaves at 85 days after transplanting (DAT). *Pseudomonas putida* and *Trichoderma atroviride* were shown to produce Indole acetic acid (IAA) in organic medium and results showed that the roots of green house tomato seedlings grown in the presence of increasing concentrations of IAA were significantly longer when seeds were previously treated with *Pseudomonas putida* or *Trichoderma atroviride* (Valerie et al., 2007).

2.2.2 Integrated nutrient source

Kumaran et al. (1998) showed that plant height and the number of branches in tomato were best with organic plus inorganic fertilizers, *azospirillum* and phosphobacteria. Provided that all nutrients are supplied by mineral fertilization, studies showed greatest plant growth responses when vermicomposts constituted a relatively small proportion (10 – 20%) of the total volume of the substrate mixture, but with higher proportions of vermicomposts in the mixture was not always improving plant growth (Subler et al., 1998 and Atiyeh et al., 2000).

Studies on the effect of vermicompost amendment to growth media for tomatoes in greenhouses either showed a maximum growth at vermicompost proportions of around 20% in the growth mixture . In an experiment with farmyard manure, vermicompost and inorganic NPK fertilizers in tomato field, it was observed that the treatment with 50% N through vermicompost and 50% N through urea recorded the highest plant height (55.6 cm) and number of branches plant $^{-1}$(7.4) and these parameters were at par with recommended NPK rate of 120:60:60 kg ha^{-1} (Reddy et al., 2002).

Application of 50% recommended fertilizer dose plus 50% farmyard manure resulted in taller plants (120.7 cm) and the highest number of primary branches plant^{-1} (8.53). The highest number of leaves plant^{-1} was obtained with 50 % recommended fertilizer dose plus 50% FYM (118.1) and 50% recommended fertilizer dose and 50% vermicompost (116.63). NPK application @ 250 kg ha^{-1} each plus farmyard manure at 38 t ha^{-1} recorded the highest values for plant height, branches plant^{-1}, clusters plant^{-1}, fruits cluster^{-1}, fruits plant^{-1} and fruit weight plant^{-1} of tomato crop in rabi season (Krishna and Krishnappa, 2002). The improvements in plant growth and increases in fruit yields could be due partially to large increases in soil microbial biomass after vermicompost applications, leading to production of hormones or humates in the vermicomposts acting as plant-growth regulators independent of nutrient supply (Arancon et al., 2003).

Rodge and Yadlod (2009) found out that integrated application of 50% recommended dose of fertilizers plus 50% farmyard manure significantly increased the plant height, number of primary branches and number of leaves at 105 days after transplanting followed by the treatment with 50% recommended fertilizer dose and 50% vermicompost.

2.3. Effect of nutrient sources on yield and yield characters

2.3.1 Organic nutrient source

In a field experiment conducted in Kerala to study the effects of enriched vermicompost on the yield and uptake of nutrients in cowpea, it was found out that enriched vermicompost was superior in terms of yield and uptake of major nutrients. Enhanced efficiency of FYM in increasing yield was revealed by Gomes et al. (1993). The usefulness of FYM in increasing crop yield is well documented (Muthuswami et al., 1990). Ismail et al. (1993) conducted a comparative evaluation of vermicompost, FYM and fertilizer on yields of bhindi and watermelon and observed an increase in yield in all the cases with vermicompost. Stoffella and Graetz (1996) reported that the total tomato yield was larger in plot amended with sugarcane filter cake compost as compared to control plots without compost. While studying the effect of different organic manures in arrowroot intercropped in coconut garden, Maheshwarappa et al. (1999) found that application of FYM resulted in significantly higher harvest index, number and length of rhizome.

Sailajakumari (1999) found the superiority of vermicompost enriched with rockphosphate on yield and quality of cowpea. Raj (1999) reported that in bhindi yield attributes like fruit number plant^{-1}, fruit weight, fruit length and fruit yield were higher in organic manure treated plots. FYM + neem cake recorded maximum number of fruits plant^{-1}, FYM + neem cake and FYM + green leaf recorded comparable and maximum yield of 158 and 153 q ha^{-1} respectively. Rao et al. (2001) studied the effect of organic manures like FYM, neem leaf, vermicompost, neem cake, azospirillum and phosphobacterium on the growth and yield of brinjal. Effect of these organic manures on growth and yield characters were better than inorganic fertilizers. Vermicompost applied to tomatoes cultivated in the field also increased yields (Goswami et al., 2001). Vermicomposts added at rates of 0, 20, 30 and 40 t ha^{-1} produced tomato yields of 114, 138, 163 and 192 t ha^{-1} compared to 56 t ha^{-1} for inorganically fertilized tomatoes.

2.3.2 Integrated nutrient source

Besford (1979) reported that flower development in tomato was accelerated by low phosphorus applications but the final number of flowers and the fruit-setting efficiency were reduced. Yield of radish, spinach and green peas were better with 50% dose of NPK through chemical fertilizers and rest through vermicompost (Jambhekar, 1996). Vermicompost application, i.e. as an organic source along with full recommended dose of NPK increases the growth and yield of okra (Ushakumari et al., 1999).

Krishna and Krishnappa (2002) found that NPK application @ 250 kg ha^{-1} plus farmyard manure at 38 t ha^{-1} gave the highest number of flower clusters plant^{-1} in tomato crop during the rabi season. Raut et al. (2003) observed maximum fruit weight (591 g) plant^{-1} and fruit yield (196.43 q ha^{-1}) in tomato when 100:50:50 kg NPK plus 20 tons farmyard manure (FYM) were applied.

The application of recommended rates of N, P and K (100, 75 and 55 kg ha^{-1} respectively) and vermicompost (12.5 quintal ha^{-1}) induced early flowering in tomato cv. Naveen whereas early picking was obtained with the application of vermicompost and phosphorus (Shukla et al., 2006). It was also found out that addition of 50% vermicompost to the growth medium made the flowering in tomato earlier by 10 days (Rodriguez et al., 2007).

2.4. Effect of nutrient sources on quality characters

2.4.1 Organic nutrient source

Studies conducted by Meire – Ploeger and Lehri (1989) revealed that plants grown with compost produced tomato fruits with higher vitamin C content. Lumpkin (1990) reported that better storage life of spinach grown with organic manure was found to be associated with lower free amino acid content, nitrate accumulation and higher protein nitrogen to nitrate nitrogen. Montogu and Ghosh (1990) found that fruit colour of tomato was significantly increased as a result of application of organic manures of animal origin.

Abhusaleha (1992) recommended equal quantity or more organic form of nitrogen for getting good quality okra fruits. Organic manures like FYM, compost, oil cakes, green leaves, poultry manure etc. improved the quality of vegetable crops like tomato, onion, gourd, chillies etc. Increase in ascorbic acid content in tomato, pyruvic acid in onion and minerals in gourds are the impact of application of organic manures to vegetable crops (Rani et al., 1997). Anitha (1997) reported that chilli plants treated with poultry manure recorded the maximum ascorbic acid content in fruits as compared to vermicompost and control treatements.

Joseph (1998) observed that in snakegourd when vermicompost was used as nutrient source, it produced fruits with more shelf life, P and K content over FYM and poultry manure. Kumaran et al. (1998) observed that quality parameters such as TSS, ascorbic acid and lycopene contents were comparatively higher in organically grown tomato plants. Premuzic et al. (1998) reported that the fruits of tomatoes grown on organic substrates such as vermicompost contained significantly more Ca and vitamin C and less Fe than those grown in hydroponics media but no changes were found in concentrations of P and K. Raj (1999) reported that crude protein content and ascorbic acid content were maximum for FYM + poultry manure and FYM + enriched compost respectively in bhindi. FYM + enriched compost and FYM + neem cake recorded comparable and lowest crude fibre content and highest keeping quality of fruits. Uma Reddy (1999) reported increase in zinc content of organically grown vegetables. Bhadoria et al. (2002) reported that protein and total mineral content of okra fruits was high, when it was treated with FYM. Worthington (2001) reported higher iron content in tomato when organically grown. He also reported that the increase in phosphorus content of organically grown vegetables may be attributed to increased availability of soil phosphorus due to the solubilizing effect of organic acids which are produced from decomposing organic manures.

Prabakaran and Pitchai (2002) observed that application of organic N sources increased pH, TSS, titrable acidity, reducing and non-reducing sugar, crude protein and ascorbic acid content of tomato over no manure control.

Omac et al. (2003) reported that cattle compost application increased freshness and vitamin C contents in melon (Cucumis melo L.). Raut et al. (2003) reported that the ascorbic acid content in fruits was the highest (16.5 mg 100 g^{-1}) when 30 tonnes FYM plus 5 kg *azospirillum* were applied $hectare^{-1}$ and it enhanced the shelf life of tomato fruits.

Patil and Madalageri (2003) revealed that a recommended dose of P_2O_5 (30 kg ha^{-1}) applied through rockphosphate along with P solubilizer, *Bacillus polymyxa* (*Paenibacillus polymyxa*) and vermicompost recorded the highest ascorbic acid content and total soluble solids (TSS) in green chillies over treatments comprising of rockphosphate with or without *Bacillus polymyxa* or vermicompost.

Increase in vitamin C was reported in organically grown vegetables (beetroot, spinach, tomato, turnip, cabbage, lettuce, carrots, apples and pears) compared to conventionally cultivated crops by Salunkhe and Desai (1988); Heaton, (2001); Worthington, (2001); Asami et al., (2003); Lumpkin, (2005) and

Uma Reddy et al., (2005). Kannan et al. (2006) reported that application of 75% vermicompost in combination with 2 kg *azospirillum* for tomato resulted in the highest yield, titratable acidity (0.72%), ascorbic acid content (23 mg 100 g^{-1}), total solids (5.4%), pH (3.9), crude protein content (1.70%) and lycopene content (3.7 mg 100 g^{-1}) and the lowest non reducing sugar content (0.37 g 100 g^{-1}).

Management practices and environmental conditions were evaluated by Lumpkin (2005) for influences on fruit quality and the development of lycopene and other antioxidant compounds in tomato and it was found that high quality tomatoes with increased levels of antioxidant compounds could be obtained from organic farms in humid subtropical conditions. Sreedevi et al. (2005) reported that vermicompost, poultry manure and cowdung application to tomato registered significantly higher crude fibre content in kharif crop, whereas in rabi, vermicompost application registered significantly higher crude fibre content compared to conventionally grown tomato crop. It was also reported that vermicompost application to tomato crop cultivated in kharif and poultry manure application in rabi registered significantly higher lycopene content compared to other organically grown tomato. Lycopene content of conventionally cultivated tomato was found to be significantly lower. Sreedevi et al. (2005) also reported that vermicompost application to tomato crop resulted in significantly higher total carotenes in rabi season compared to other organically cultivated crops and cowdung application to kharif tomato crop registered significantly higher total carotenes.

Federico et al. (2007) reported that the addition of vermicompost increased the amounts of soluble and insoluble solids in tomatoes significantly. The total nitrogen contents of tomatoes were not affected by addition of vermicompost. Rodriguez et al. (2007) found out that addition of 50% vermicompost to the growth medium increased the soluble solids in tomato.

'Tolstoi' tomato (*Lycopersicon esculentum*) when grown in organic nutrient solution of 100% and 50% vermicompost gave fruits with high ascorbic acid content than those obtained from plants grown in inorganic media (Shweta and Deepika, 2007). Prabhakaran (2008) proved that application of organic nitrogen sources to the soil for tomato improved the quality parameters of tomato. They also showed that fruits grown on organic substrates contained significantly more Ca and less Fe than did the fruits grown on inorganic media.

Sable et al. (2007) observed that TSS and Vitamin C contents were more in treatments where 50% nitrogen through neem cake and 50% N through vermicompost as well as 25% N through neem cake and 75% N through vermicompost were given together. Pieper and Barrett (2009) also found that the total and soluble solids were significantly higher and consistency was greater in organic tomatoes.

2.4.2 Integrated nutrient source

Shanmughavelu (1989) pointed out that the application of a combination of FYM and inorganic mixture was the best for firmness, storage life and keeping quality of tomatoes for a long time. Almazov and Kholuyako (1990) found increased sugar content in tomatoes due to the application of NPK along with peat compared to the application of NPK alone. Vasanthi and Kumaraswami (1996) reported highest concentration of micronutrients in the treatements that received vermicompost along with NPK fertilizer compared to the treatments that received NPK alone. Application of 75% nitrogen as urea along with 25% as FYM resulted in bunch trait that are on par with bunches produced when inorganic sources was used alone to provide required nitrogen. Rodge and Yadlod (2009) found out that the fruit juice, TSS and ascorbic acid contents were significantly more in case of integrated application of 50% recommended fertilizer dose plus 50% farmyard manure.

2.5. Effect of nutrient sources on shelf life

2.5.1 Organic nutrient source

Sreedevi et al. (2005) reported that among the organically and chemically cultivated tomato crops, vermicompost applied tomato crop registered significantly higher shelf life when stored at room temperature in kharif season. In rabi season, tomato crop cultivated with vermicompost and poultry manure when stored at both room temperature and refrigerated temperature registered significantly higher shelf life compared to other organically and conventionally grown crops. Sable et al. (2007) observed that more shelf life for fruits was recorded in treatments where 50% nitrogen through neem cake and 50% N through vermicompost as well as 25% N through neem cake and 75% N through vermicompost were given together.

2.5.2 Integrated nutrient source

Shanmughavelu (1989) pointed out that the application of a mixture of FYM and inorganic fertilizer mixture was found to be the best for firmness, storage life and keeping quality of tomato for a long time. The number and weight of unmarketable fruits after 10 days of storage from harvest of green chillies increased with increasing rates of NPK along with FYM (Nair and Peter, 1990). Shelf life of fruits under room temperature was more (4 days) when nitrogen nutrition was given through 2:1 ratio of organic – chemical nitrogen using poultry manure as organic source in equivalent nitrogen basis (Rajasree, 1999).

Application of 150 kg nitrogen in the form of pressmud recorded higher shelf life period of 8.3 days for tomato fruits (Prabhakaran, 2008). But application of 150 kg nitrogen in the form of urea decreased the shelf life (3.1 days) of fruits. Rodge and Yadlod (2009) found out that the shelf life of fruits was maximum for the treatment with 50% recommended fertilizer dose and 50% vermicompost.

2.6. Effect of nutrient sources on availability of nutrients

2.6.1. Organic nutrient source

Kanwar and Prihar (1982) reported that continuous application of FYM increased the organic carbon as well as nitrogen content of soil. Muthuvel et al.

(1985) and Srivastava (1985) reported an increase in the available nitrogen content of the soil and increased nitrogen recovery due to organic sources of nitrogen. The earthworm casts or vermicompost is high in bacteria, organic matter, total and nitrate nitrogen, available P and K (Gaur, 1984 and Brady, 1996). Available K increased slightly with the addition of FYM for a long time (Sharma et al., 1984). Sharma and Sharma (1988) compared the effect of FYM and green manure and inferred that there was a build up of available K which was maximum with the use of FYM than green manure. Available phosphorus content of soil was significantly increased with incorporation of FYM.

Badanur et al. (1990) reported that available P content of soil was significantly increased with the incorporation of subabul, sunhemp loppings and FYM. Haimi and Hahuta (1990) reported that earthworms increased the proportion of mineral N availability for plants at any given time although N was clearly immobilized in the initial stages. Kabeerathumma and Mohankumar (1990) in a long term manurial experiment observed an increase in nutrients like N, P, K and organic carbon with the inclusion of FYM and application of respective nutrients to the soil. More (1994) reported that addition of farm wastes and organic manures increased the status of available N and available P of the soil. Dhanorkar et al. (1994) reported that continuous use of FYM raised the available K by 1.3 to 5.4 folds over control. Reddy and Mahesh (1995) could obtain increased availability of N and K in soil by the application of vermicompost compared to FYM.

Among the sources of organic manures, vermicompost has a special place because of the presence of readily available plant nutrients, growth enhancing substances and number of beneficial microorganisms like nitrogen fixing, P solubilising and cellulose decomposing organisms (Sultan, 1997). Vermicompost have been demonstrated to be valuable soil amendments that offer a balanced nutritional release pattern to plants providing nutrients such as available N, soluble K, exchangeable Ca, Mg, and P that can be taken up readily by plants (Edwards and Fletcher1988;Edwards, 1998).

Significantly lower nitrogen content was observed in tomato crop with cowdung application. The lower absorption of nitrogen content by the crops from the organic manure i.e., FYM might be attributed to the non availability of adequate nutrients throughout the crop growth period due to the slow release of nitrogen from applied manures (Uma Reddy, 1999).

The use of organic amendments to soil has long been recognized as providing a more balanced and better-timed source of nutrition for plant growth through the gradual decomposition of the organic matter by microorganisms and slower mineralization and release of nutrients that it contains (Pascual et al., 1997; Zink and Allen, 1998). The organic matter in vermicomposts can usually provide plants with a balanced source of nutrients that can influence the composition and physiology of plants. Phosphate solubilizing microorganism and vermicompost however increased the availability of high- grade phosphate rock in soil (Chandra et al; 2004).

2.6.2. Integrated nutrient source

Raj (2006) had reported that combined application of organic manures showed considerable residual effect in improving available nitrogen content of soil compared to the sole application of manures.

2.7. Effect of nutrient sources on uptake and content of nutrients

2.7.1. Organic nutrient source

Conventionally grown tomato registered significantly higher nitrogen content compared to organically treated crops (Uma Reddy, 1999). She also reported significantly lower nitrogen content in tomato crop with cowdung application. The lower absorption of nitrogen content by the crops from the organic manure i.e., FYM might be attributed to the non availability of adequate nutrients throughout the crop growth period due to the slow release of nitrogen from applied manures. Ganguly (1988) reported the beneficial effect of FYM on the uptake of all nutrients in maize. Minhas and Sood (1994) opined that FYM application was beneficial in enhancing the uptake of all three major nutrients by potato and maize.

Patil and Madalageri (2003) revealed that a recommended dose of P_2O_5 (30 kg ha^{-1}) applied through rockphosphate along with P solubilizer, *Bacillus polymyxa* (*Paenibacillus polymyxa*) and vermicompost recorded the highest P uptake in green chillies over treatments comprising of rockphosphate with or without *Bacillus polymyxa* or vermicompost. In bhindi, nitrogen and phosphorus uptake was the highest for FYM and neem cake whereas K uptake was maximum for FYM + poultry manure with 150 kg ha^{-1} of N and with azospirillum inoculation. Sharma et al. (2009) reported that in bhindi nutrient uptake increased significantly with increasing levels of vermicompost as well as FYM. Rajeswari and Shakila (2009) demonstrated that application of FYM 10 t ha^{-1} and vermicompost (2.5 t ha^{-1}) along with Panchagavya (3 per cent as foliar spray) significantly enhanced the uptake of N,P and K in palak.

Conventionally grown tomato registered significantly higher potassium content compared to organically grown vegetables (Hannaway et al., 1980). Conventional potassium fertilizers dissolve readily in soil water in large quantities while organically managed soils hold moderate quantities in the root zone of the plant and higher potassium fertilizer can reduce the absorption of magnesium and phosphorus content.

2.7.2. Integrated nutrient source

In Soybean, uptake of N at flowering and harvesting stages were significantly enhanced due to the increased level of phosphorus and FYM (Nimje and Seth, 1988). Sharma et al. (1988) noticed higher uptake of nitrogen by rice with the application of organic manure along with increasing doses of inorganic nitrogen. Zhao shi-wei and Huomg Fu Zhan (1988) demonstrated that chemical fertilizer application along with vermicompost increased the nutrient uptake and net production of wheat and sugarcane. Organic manures applied in conjuction with optimal NPK dose resulted in the highest K uptake by crops (Sarkar et al., 1989; Singh and Tomar, 1991).

The uptake of nitrogen and phosphorus was greater in the treatment combination of half inorganic and half organic, particularly from poultry manure. The highest K uptake was observed in plants applied with equal quantities of organic and inorganic nitrogen (Abhusaleha, 1992). Application of FYM at 25 t ha^{-1} along with 75 per cent of the recommended dose of inorganic fertilizer and vermicompost at 5 t ha^{-1} recorded the highest nutrient uptake in bhindi (Barani and Anburani, 2004).

2.8. Economics of organic manuring of crops

Bharadwaj (1995) reported that total returns on organic farming were higher than from other systems due to high premium on standard product prices. A study on the benefit-cost ratio analysis of ginger indicated that application of FYM @ 48 t ha^{-1} recorded the highest return of Rs. 1,20245 and B:C ratio of 2.32 : 1 (KAU, 1999). Raj (1999) observed that application of FYM along with neem cake (150 kg ha^{-1}) and azospirillum recorded the highest fruit yield and profit in bhindi. This treatment gave an additional profit of 32.04 per cent over control (POP recommendation of KAU).

Maximum net return with a benefit: cost ratio of 2.30 was obtained when 100:50:50 kg NPK plus 20 t ha^{-1} farmyard manure (FYM) were applied to tomato (Raut et al., 2003). Application of poultry manure / neem cake / FYM to supply 100 kg N ha^{-1} (N equivalent basis) in combination with a seedling dip of azospirillum and foliar application of 2% pseudomonas combined with cow's urine spray at 5% concentration was the best economic organic nutrient schedule for increasing the productivity of bhindi (Geethakumari, 2005). Prabhakaran (2008) observed that application of organic nitrogen in the form of 150 kg N as urea to the soil increased the net returns, gross returns and benefit- cost ratio of tomato cultivation to 5.2. Shekhar and Rajasree (2009) observed that among the treatments, application of FYM at 20 t ha^{-1} resulted in a higher B:C ratio in bhindi (3.56) compared to the lower levels.

2.9. Effect of spacing on growth characters, productivity and quality

Plant growth was strongly influenced by plant density, the highest plant growth rate occurring at the lowest plant density. The same has been observed by De Koning and De Ruiter (1991). Reduced plant growth at increased plant density can be explained by reduced light interception $plant^{-1}$ (less space available and lower leaf area $plant^{-1}$). Papadopoulos and Ormrod (1991) reported that plant height and internode length increased significantly with successive decreases in plant spacing. Fekadu and Teshome (1998) reported that when tomatoes were grown at spacing of 35, 50 and 70 cm between plants there was not any significant effect on plant height and fruit size.

De Koning and De Ruiter (1991) observed an increase in flower abortion at higher plant densities. Papadopoulos and Ormrod (1990) reported that fruit set rate (per cent of total number of flowers set into fruits) was not affected in tomato by plant spacings except at extreme shading conditions. They also reported that the total and marketable yield $plant^{-1}$ declined linearly with successive increases in plant density from 3 to 11 plants m^{-2}. Cockshull et al. (1992) reported that with increasing plant density the flowering and fruit ripening was delayed up to seven days. They also reported that shade increased the proportion of fruit in the small size grade even in the first few weeks of production. He concluded that smaller fruits were produced because the supply of assimilate was reduced proportionately more than the reduction in fruit number. The number of leaves preceding the first inflorescence may be expected to rise at high plant densities due to the low light environment found in such crop stands (Dieleman and Heuvelink, 1992).

Cockshull and Ho (1995) reported that the overall weight of marketable tomato fruits produced $plant^{-1}$ fell from 19.7 kg at low density to 15.1 kg at high density which was consistent with the linear decline in fruit size with increasing plant density. When the sink /source ratio was low, a sufficient amount of assimilates was available for young fruits to start growing. However, with increasing fruit load and/or decreasing Photosynthetic Photon Flux Density (PPFD), the sink/source ratio increased resulting in the abortion of young fruits. The duration of fruit development was unaffected by shade.

Tanaka and Komochi (1982) studied the relationship between plant density and topping on the growth and yield of tomato in greenhouse. With increasing plant density, fruit ripening was delayed up to 7 days. The production of smaller fruit under shade has also been noted by Bailey and Hunter (1988). Linear decline in fruit size with increasing plant density was observed by Papadopoulos and Ormrod (1990).

2.10. Residual effect of organic manures

About less than 30% of nitrogen and small fraction of phosphorus and potash in organic manure may become available to immediate crop and rest to subsequent crops (Gaur, 1984). In contrast to chemical fertilizers the availability of nutrients present in bulky organic manures such as FYM is quite slow. In the case of FYM only one half of the nitrogen, one sixth of the phosphoric acid and a little more than one half of the potash alone are readily available to plants during the first season of application (Thampan, 1993). The rest of the plant nutrients become available to the subsequent crops. The low availability of nutrients present in FYM, compost etc. is beneficial in the sense that the availability is spread over a number of crop seasons and as such, the nutrients are well protected from different forms of losses.

The residual availability of N, P, K and organic carbon as a result of vermicompost application was reported by Kadam (2000). Sharu (2000) observed high residual soil K in plots, which received higher level of neem cake along with chemical fertilizer (3:1). Yaduvanshi (2000) reported that the application of FYM to kharif crop gave significant residual effect on the grain yield of succeeding wheat crop.

The residual effect of FYM, fertilizer and biofertilizer on wheat during two seasons was studied by Patidar and Mali (2002). Application of 10 t ha^{-1} FYM and 75 per cent or 100 per cent recommended dose of fertilizer (N and P) to sorghum during rainy season had significant residual effect on succeeding wheat crop and increased grain yield of wheat.

Chattoo et al. (2009) studied the residual effect of organic manures on succeeding crop pea, it was revealed that organic integration recorded higher values of plant height, pod number $plant^{-1}$, pod yield $plant^{-1}$, pod yield ha^{-1} and nodule number $plant^{-1}$ with treatment consisting of FYM (6 t ha^{-1}) plus sheep manure (4 t ha^{-1}) plus poultry manure (1 t ha^{-1}) plus vermicompost (1 t ha^{-1}) plus biofertilizer (7 kg ha^{-1}).

2.11. Residual crop study of amaranthus

Alam et al. (2007) studied the effect of vermicompost and NPKS fertilizers on growth and yield of red amaranth. Application of various amounts of vermicompost (2.5, 5, 10 t ha^{-1}) with NPKS fertilizers (50 per cent and 100 per cent) increased the vegetative growth and yield of red amaranth. The results showed that effects of vermicompost are more efficient for the vigorous production of red amaranth. Assessing the efficacy of vermicompost produced from organic waste over chemical fertilizers on the growth of amaranthus plants based on their physical parameters on the whole, Malathi and Uma (2009) reported that vermicompost produced best results over chemical fertilizer. Good survival rate (96 per cent) was observed with excess application of vermicompost on amaranthus plant and low percentage survival (16 per cent) was seen with excess application of chemical fertilizer. Humic materials and other plant growth-influencing substances such as plant growth hormones produced by microorganisms during vermicomposting might have been responsible for the increased amaranthus growth and yield.

In an experiment to study the effect of organic, organo-mineral and NPK fertilizer on nutritional quality of amaranthus, Makinde et al. (2010) reported that organic fertilizers had more residual effect than NPK fertilizers. Organic materials alone or combined with NPK reduced the crude fibre content especially on residual basis. Compared with organic materials NPK gave least values of crude protein content, ash and crude fibre. Organic fertilizers maintained adequate crude protein content in first and second crops whereas NPK did not maintain adequate crude protein in the second crop. Generally the organic materials alone or combined with NPK increased ash significantly in first and second crop of amaranthus. Therefore the organic materials used alone or combined with NPK at reduced levels sustained good nutritive quality of amaranthus as opposed to NPK fertilizers alone and there was residual effect of fertilizers in soil. The organic materials had residual effect on protein ether extract and ash content in first and second crops. They are recommended for use in cultivation of amaranthus. In an experiment with organic fertilizers, results showed that the second crop of amaranthus grown without further additions of organic fertilizer yielded only 50-60 per cent of the first crop indicating the need for repeated applications of organic fertilizers to sustain yields.

MATERIALS AND METHODS

3. MATERIALS AND METHODS

A field experiment was conducted at the Instructional Farm attached to the College of Agriculture, Vellayani during 2009- 2010 to study the effects of organic nutrition and spacing and their interactions upon growth, yield, quality and nutrient uptake of tomato. In order to study the residual effect, a crop of amaranthus (*Amaranthus tricolor*) was also raised after tomato in the same field. The details of the materials used and methods followed are presented in this chapter.

3.1 Experimental site

The experiment was conducted in the garden land of the Instructional Farm attached to the College of Agriculture, Vellayani. The farm is situated at 8.5^0N latitude and 76.9^0E longitude, at an altitude of 29 m above mean sea level.

3.1.1 Soil

The soil of the experimental site was red loam belonged to Vellayani series under the order oxisol. The important physical and chemical properties of the soil are given in Table 3.1. The soil is acidic with a pH of 5.1. The fertility status of soil was classified as low in available nitrogen (N), high in available phosphorus (P) and medium in available potassium (K).

Table 3.1. Soil characteristics of the experimental site

A. Physical properties

Characteristics	**Content**	**Methodology**
Mechanical composition		
Clay	27.20 %	International pipette method (Piper, 1966)
Silt	21.60 %	

Fine sand	19.30 %	
Coarse sand	31.70 %	
Textural class	Sandy clay loam	
pH	5.1	pH meter with glass electrode (Jackson, 1973)
Bulk density (Mg m^{-3})	1.6	Core method (Gupta and Dakshinamoorthy, 1980)
Soil aggregation	42.77	Wet sieving (Gupta and Dakshinamoorthy, 1980)
Porosity (%)	32	(Gupta and Dakshinamoorthy, 1980)

B. Chemical properties

Properties	**Mean**	**Status**	**Methodology**
Organic carbon (%)	0.574	Low	Walkley and Black's rapid titration (Jackson, 1973)
Available N (kg ha^{-1})	233	Low	Alkaline Permanganate method (Subbiah and Asija, 1956)
Available P_2O_5 (kg ha^{-1})	73.57	High	Bray Colorimetric Method (Jackson, 1973)

Available K_2O (kg ha^{-1})	132.5	Medium	Ammonium acetate method (Jackson, 1973)

3.1.2. Season

The main crop (tomato) season lasted from 7th November 2009 to 4th March 2010 covering a period of 118 days and the residual crop (amaranthus) season lasted from 9th March to 18th April 2010 which coincided with the hottest summer.

3.1.3. Weather conditions

Vellayani experiences warm humid tropical climate. The rainfall received during the main crop (tomato) season from 7th November 2009 to 4th March 2010 was 435.10 mm distributed over a period of 118 days and the rainfall received during the residual crop (amaranthus) period from 9th March to 18th April 2010 was only 31.8 mm distributed over a period of 41 days. The detailed weather data including mean maximum and minimum temperatures (^{0}C), rainfall (mm) and relative humidity (%) during the cropping period are given in appendix and graphically presented in Fig. 1.

3.1.4. Cropping history of the field

The field was under a bulk crop of organic bhindi four months prior to the conduct of the experiment.

3.1.5. Variety

The main crop variety used was 'Vellayani Vijai' released in 2006 from the College of Agriculture, Vellayani. It was an introduction and selection from CLN1621F (AVRDC, Taiwan). It is high yielding with a yield potential of 37.26 t ha^1, compact and an early maturing variety. It is resistant to bacterial wilt disease which is a menace in tomato cultivation.

The residual crop (amaranthus) variety used was Arun. It was released in

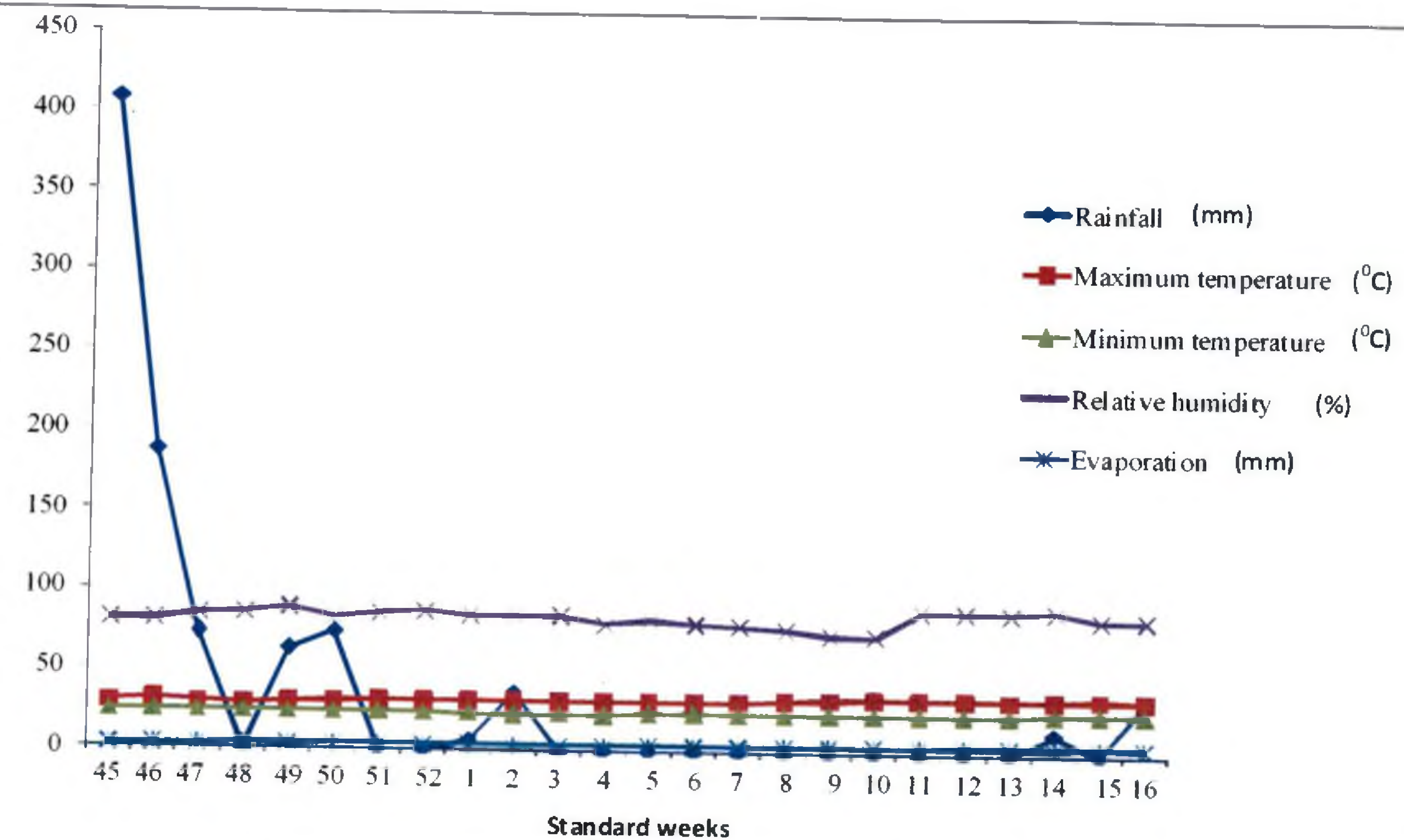

Fig 1. Weather data during the cropping period (November 2009 to April 2010)

1992 from the College of Agriculture, Vellayani. Its pedigree was from Palapoor local (MS). The crop can be transplanted three weeks after sowing and 2 to 3 ratoons can be taken from a single crop. The crop will be ready for harvest in 45 days after sowing (DAS).

The seed materials of both the main crop and residual crop were obtained from the Department of Olericulture, College of Agriculture, Vellayani.

3.2. Methods

3.2.1. Main Crop - Tomato

3.2.1.1. Nursery

25 g seeds were sown in well prepared raised nursery beds of size 1.2 m wide and 15 cm high with channels around them to facilitate the drainage of excess water. The bed was prepared with a basal dressing of powdered cattle manure and sand in 1:1 proportion at the rate of 1 kg m^{-2}. For seed treatment *Pseudomonas fluorescence* culture developed by Kerala Agricultural University (KAU) was used.

The seeds were sown on 7th November 2009. Before sowing, the seeds were pelleted with 5 g of *Pseudomonas fluorescens* culture as an organic prophylactic measure against bacterial wilt disease. Pelleting was done by hand after a slight wetting of the seeds with water. The pelleted seeds were dried in shade for 10 minutes and then sown to beds. North East Monsoon prevailed during the period and hence the nursery beds were covered with dried coconut leaves to prevent damage of seedlings from the severity of rains. Irrigation was not required frequently because of the prevailing rains. Hand weeding was done periodically. The seedlings were ready for transplanting within 33 days by 10th December 2009. Before transplanting, the seedlings were given a root dip in *Pseudomonas fluorescence* culture for a period of 10 minutes. It also acted as an organic prophylactic measure against bacterial wilt disease. For the purpose 250 g of pseudomonas culture was diluted in 750 ml water at a concentration of 33.33%.

3.2.1.2. Main Field

3.2.1.2.1. Design and Layout

Design	:	4 x 3 Factorial RBD
Replications	:	3
Treatments	:	12
Number of plots	:	36
Plot size	:	2.4 m x 1.8 m
Plot area	:	4.32 m^2

Number of plants $plot^{-1}$

S_1 - 20

S_2 - 25

S_3 - 35

The field lay out of the experiment is shown in Fig. 2.

3.2.1.2.2. Treatments

The treatments consisted of combinations of four levels of nutrients and three spacing.

1. Nutrient levels (4)

N_1: Full recommended dose – 200 kg N^* (as FYM and enriched vermicompost at 1:1 ratio)

N_2: 75 % recommended dose only – 150 kg N (as FYM and enriched vermicompost at 1:1 ratio)

N_3: 50 % recommended dose only – 100 kg N (as FYM and enriched vermicompost at 1:1 ratio)

Fig 2. Layout plan of the experiment

N_4S_1	N_3S_2	N_4S_2	N_3S_1
N_1S_1	N_3S_3	N_1S_3	N_2S_2
N_2S_1	N_1S_2	N_4S_3	N_2S_3
N_3S_1	N_1S_3	N_3S_2	N_3S_3
N_1S_2	N_2S_3	N_4S_3	N_2S_1
N_4S_1	N_1S_1	N_4S_2	N_2S_2
N_2S_2	N_3S_2	N_3S_1	N_3S_3
N_4S_1	N_1S_3	N_4S_2	N_2S_1
N_1S_1	N_2S_3	N_1S_2	N_4S_3

I← 2.4 m x 1.8 m

N_4: POP recommendation - FYM – 25 t ha^{-1} + NPK @ 75: 40: 25 kg ha^{-1}

2. Spacing (3)

S_1 : 60 cm x 60 cm

S_2 : 60 cm x 45 cm

S_3 : 60 cm x 30 cm

* Note : 200 kg N – Nitrogen content of FYM (25 t ha^{-1}) = 125 kg N ha^{-1}

Recommended dose : 75 kg N

The following treatments were applied commonly:

1. 3% neem seed oil-garlic emulsion spray from transplanting onwards at frequent intervals.

2. Pseudomonas spraying at frequent intervals @ 10 g l^{-1}

3. Trichoderma incorporation in the soil at the time of transplanting

4. Uniform mulching in the initial stage

5. Uniform irrigation as and when required

3.2.1.3. Details of cultivation

3.2.1.3.1. Land preparation

The main field was dug twice and plots of 2.4 x 1.8 m were laid out with bunds of 50 cm width all around. Individual plots were again dug, mixed with the organic treatments fully as basal and levelled perfectly. The treatments were allotted randomly using random numbers as shown in Fig. 2.

3.2.1.3.2. Planting of seedlings

Tomato seedlings of 30 days old treated in pseudomonas culture were planted. Utmost care was given for the seedlings initially by providing them necessary shade as protection from direct sunlight. For this purpose shading was done with dried coconut leaves. Uniform irrigation was provided afterwards.

Proper care was taken during the initial week after transplanting to prevent crop failure.

3.2.1.3.3. Application of fertilizer

Organic nutrition with FYM and rockphosphate enriched vermicompost were the source of nutrients for the treatments N_1, N_2 and N_3. They were applied as basal dose and hence incorporated in the soil at the time of layout itself. N_4 was the control treatment with FYM and chemical fertilizers (POP recommendation). Urea, Mussooriephos and Muriate of potash (MOP) were used for the purpose. Trichoderma was incorporated and multiplied with neem cake upon the FYM used for treating N_1, N_2 and N_3 and is discussed below.

3.2.1.3.4. Trichoderma mass multiplication

Dry neem cake and cowdung were powdered and mixed to get a coarse texture and then moistened by sprinkling water. The commercial preparation of *Trichoderma spp* (available in polythene packets) @ 1-2 kg 100 kg^{-1} of neem cake – cowdung mixture was added. After thoroughly mixing, it was covered with a perforated polythene sheet or ordinary newspaper and kept in shade for 4 -5 days for multiplication. Again mixed well and kept for 3 more days for further multiplication. This preparation was ready for incorporation in the soil. Cowdung alone can also be used as the food base, but since neem cake is found to be a better substrate, the incorporation of neem cake to cowdung at the ratio of 1:10 (w/w) is better than using cowdung alone. If cowdung alone is used, mixing has to be done at 5 days interval and it will be ready to use only on the 15^{th} day. Trichoderma incorporated neem cake - cowdung mixture can be used along with potting mixture in nursery beds and also in the field, i.e., wherever cowdung is used as a manure (KAU, 2002).

3.2.1.3.5. Preparation of rockphosphate enriched vermicompost

Vermicomposting was carried out in pits of size 2 x 1 x 0.5 m^3 using the abundantly available local raw material viz., banana leaves and banana pseudostem. Banana leaves and pseudostem were chopped and mixed with cowdung in the ratio 8:1 on volume basis and the pit was filled with this mixture and earthworm species *Eudrillus eugeniae* was released into the pit (KAU, 2002). Rockphosphate was added to the biowastes at the rate of one per cent of the weight of the raw material at the time of filling the pit. After 15 days, *a*zospirillum and phosphobacter were inoculated each @ 1 kg $ton^{-1}$of material and adequate turning was given. Adequate moisture level (about 45%) was maintained by sprinkling water every alternate day and when compost is ready by its physical appearance denoted by the development of a dark brown to black colour with uniformly disintegrated structure, watering was stopped. After completion of composting (60 days) compost was removed from top, air dried and stored in gunny bags (Asha, 2006).

3.2.1.3.6. Maintenance of the crop

Gap filling was done on the 5^{th} day after transplanting. The crop was hand weeded thrice at 25 days interval. The crop was given uniform irrigation periodically except at times of rainfall. The general stand of the crop was good. The crop was maintained organically throughout. Monthly prophylactic spraying of *Pseudomonas fluorescens* @ 10 g $litre^{-1}$ was carried out as an organic preventive measure against bacterial wilt. The crop was also given monthly prophylactic spray of 3% neem seed oil-garlic emulsion as an organic pest repellent during the initial two months after planting and in the third month at fruit set, frequent spraying, i.e., once in two weeks in order to repel fruit borer attack which became prevalent during the fruiting period.

3.2.1.3.7. Preparation of neem seed oil-garlic emulsion

To prepare 10 litres of 2% neem seed oil-garlic emulsion, 200 g of garlic and 50 g ordinary bar soap are required. Slice the bar soap and dissolve in 500 ml luke warm water. Grind 200 g of garlic and take the extract in 300 ml water. Pour the 500 ml soap solution in 200 ml neem seed oil slowly and stir vigorously to get a good emulsion. Mix the garlic extract in the neem seed oil-soap solution. Dilute this 1 litre stock solution by adding 9 litres of water to get 10 litres of 2% neem seed oil-garlic emulsion (KAU, 2007).

3.2.1.3.8. Harvesting

Different treatments showed different timings of harvest and the number of harvests also differed with the treatments. The crop was ready for first harvest at 90 to 100 DAS which varied with the treatments. The number of harvests also varied accordingly from 3 to 8.

3.3 Observations

3.3.1. Growth characters

The observations were taken from five randomly selected observation plants from each treatment eliminating the border row plants. The important biometric observations included plant height, number of leaves, leaf area index (LAI), number of branches and dry matter production (DMP). The observations were recorded on the same plants at three different growth stages viz., two weeks after transplanting (2WAT), i.e., the initial stage of the crop, at flowering stage (4 WAT) and at the first harvest stage. Unlike other observations, DMP was taken only after the final harvest from the observation plants in each plot.

3.3.1.1. Plant height (cm)

The height of the plants was measured from the base to the growing tip of the plants. The mean height obtained in each treatment was taken as the true height of the plant $plot^{-1}$.

3.3.1.2. Leaves $plant^{-1}$

The total number of leaves $plant^{-1}$ was taken from the same observation plants in each treatment plot. The mean number of leaves obtained in each treatment was taken as the true leaf number of the plants $plot^{-1}$.

3.3.1.3. Branches plant^{-1}

The total number of branches and secondary branches in the plants were observed from the same observation plants in each treatment plot. The mean number obtained in each treatment was taken as the true number of branches of plant plot^{-1}.

3.3.1.4. Leaf Area Index (LAI)

The LAI was worked out by linear measurement of leaves suggested by Montgomery (1911). The leaf area was calculated using a general relationship A=b×I×W where b is a coefficient. Such a mathematical equation for estimating leaf area reduces sampling effort and cost, may increase precision where samples are difficult to handle.

The LAI was calculated by the following formula developed by Watson (1947).

$$LAI = \frac{\text{Leaf area plant}^{-1}\ (\text{cm}^2)}{\text{Land area occupied by the plant}\ (\text{cm}^2)}$$

Length and breadth of two leaves from the bottom, middle and top of the plants from each of the observation plants were taken in case of all treatment plots, leaf area determined and the LAI was worked out using the above formula. The mean LAI obtained in each treatment was taken as the true LAI of the plant plot^{-1}.

3.3.1.5. Dry matter production (DMP)

Unlike the above observations, DMP was determined only after the final harvest from the observation plants in each treatment plot. The dry weights of shoot, root and fruits of the observation plants from each treatment were recorded. The samples were dried to constant weights in a hot air oven at a temperature of 70^0C and then the dry weights were taken. The mean weight obtained in each treatment was taken as the true dry weight of the plants plot^{-1}. The dry weight was expressed in gram plant^{-1}.

3.3.2. Flower and flowering characters

3.3.2.1. Days to first flowering

The observation was recorded from the observation plants in each treatment plot. Keen observation was required for this purpose. The days to first flowering varied with the treatments. The mean days obtained in each treatment was taken as the true days to first flowering of the plant plot^{-1}.

3.3.2.2. Flowering intensity

The observation was recorded from the plants of the net plot area in each treatment at 45, 55, 65 and 75 DAS (13, 23, 33 and 43 DAT respectively). It was determined by finding out the ratio of the number of plants bearing flowers to the total number of plants observed and expressed as percentage.

3.3.2.3. Flowers plant^{-1}

The observation was taken from the observation plants in each treatment plot at 45, 55, 65 and 75 DAS (13, 23, 33 and 43 DAT respectively). The mean number of flowers obtained in each treatment was taken as the reference number of flowers of the plants plot^{-1}. The mean number of flowers plant^{-1} at 75 DAS (43 DAT) was taken for granted as the total number of flowers plant^{-1} in each treatment plot.

3.3.2.4. Flowering branches plant^{-1}

The observation was taken from the observation plants in each treatment plot at 75 DAS (43 DAT). The mean number obtained in each treatment was taken as the true number of flowering branches in the plant plot^{-1}. The number of flowering branches plant^{-1} equals the number of fruiting bunches plant^{-1}.

3.3.2.5. Flowers bunch^{-1}

The observation was taken from the flowering bunches of the observation plants in each treatment plot at 75 DAS (43 DAT). The mean number obtained in each treatment was taken as the true number of flowers bunch^{-1} in the plants plot^{-1}.

3.3.3. Fruit and fruiting characters

3.3.3.1. Fruiting intensity

The fruiting intensity was determined at 60, 70, 75 and 90 DAS (28, 38, 43 and 58 DAT respectively) in each treatment plot from the plants in the net plot area by finding the ratio of the fruit bearing plants in the net area to the total observed plants in the area and expressed in percentage.

3.3.3.2. Fruits plant^{-1}

All the observation plants had put fruits which made it easy to take fruiting observations. Number of fruits plant^{-1} was determined at 90 DAS (58 DAT respectively) from each reference plant for all treatment plots. The mean number of fruits seen in each treatment was taken as the reference number of fruits of the plants plot^{-1}. The mean number of fruits obtained plant^{-1} at 90 DAS (58 DAT) was taken for granted as the total fruits plant^{-1} in each treatment plot.

3.3.3.3. Fruits bunch^{-1}

The observation was taken from the fruiting bunches of the observation plants in each treatment plot at 90 DAS (58 DAT). The mean number obtained in each treatment was taken as the true fruit number bunch^{-1} in the plants plot^{-1}.

3.3.3.4. Percentage fruit setting

This observation was determined by dividing the total number of fruits on a plant with the total number of flowers produced in the same plant marked from the observation plants in each treatment plot. The mean percentage obtained in each treatment was taken as the true fruit setting percentage of the plants plot^{-1}.

3.3.3.5. Days to maturity of fruits

This was observed by tying a tag to the fertilized flower in each plant. Two fertilized flowers in each plant were tagged for the purpose. The period from fruit set to initial yellowing of the fruit was determined. The mean days required in each treatment was taken as the true days to maturity of fruits of the plants $plot^{-1}$.

3.3.3.6. Days to first harvest

It varied with the treatments and was observed on the observation plants in each treatment plot and the mean days required in each treatment was taken as the true days to first harvest of the plants $plot^{-1}$.

3.3.3.7. Number of harvests

The observation was recorded by counting the number of harvests upon the observation plants in each treatment plot.

3.3.3.8. Fruit yield

The plants in the net plot area in all treatment plots were screened for the purpose. All fruits obtained from the plants in net plot area were weighed and the yield was expressed in tons $hectare^{-1}$ ($t\ ha^{-1}$). The observation plants were also screened for getting the average fruit yield in grams $plant^{-1}$. The mean weights of all the fruits obtained $plant^{-1}$ upon the observation plants in each treatment plot was taken for granted as the fruit yield $plant^{-1}$ $plot^{-1}$.

3.3.3.9. Average fruit weight

This was determined by dividing the total yield obtained from each plant to the total number of fruits harvested from the particular plant. Observation was made upon the fruits of observation plants in each treatment plot and the mean weights in grams obtained in each treatment was taken for granted as the reference fruit weight of the plants $plot^{-1}$.

3.3.4. Quality characters

3.3.4.1. Fruit girth

Six fruits from each of the observation plants were taken whose girth was determined using a thread. The thread was wound around the middle portion of the fruits and the length of the thread was measured in a meter scale. The mean girth obtained in each treatment was taken as the reference fruit girth of the plants plot^{-1}.

3.3.4.2. Days to colour change of the fruit from yellow to red

Keen observation was required for noting the days to colour change of fruits from yellow to red. Three fruits each from the observation plants were tagged after their yellowing and the days for their colour change from yellow to red was observed. The mean days to colour change in each treatment was taken as the true days to colour change of fruits of the plants plot^{-1}.

3.3.4.3. Shelf life of fruits

Fruits obtained from the observation plants were used for storage studies. Three mediums viz., open air, 30 microns plastic cover and brown paper cover were used to determine the shelf life of fruits. Four sets of fruits were stored in each of the above medium with 6 fruits in each set. Their storage life was determined by examining the daily percentage damage within the stored set of fruits. The mean days of storage until there occurred 100% damage of them was recorded in case of each treatment.

3.3.4.4. Organoleptic tests

Organoleptic tests via visual observation and taste were determined upon the fruits obtained from the observation plants. The scores given for the observations were one for low quality, two for medium quality and three for the best quality. The visual organoleptic tests included scoring for size and colour.

Organoleptic scoring was also carried out for the taste of fruits. The fruits were made to taste with the help of three people and mean scores were given accordingly. Five fruits each from a plant were used for organoleptic studies.

3.3.4.5. Vitamin C

Vitamin C content of the fresh ripe fruits was estimated by titrimetric method (Paul Gyorgy and Pearson, 1967) and expressed in mg 100 g^{-1} of fresh ripe fruits.

3.3.4.6. Total Soluble Solids (TSS)

The TSS content of mature green fruits as well as fresh fully ripe fruits was determined using Erma hand refracto meter (pocket type) and expressed in degree brix (^{0}B). The fruits obtained from the observation plants were used for the purpose. The mean TSS content was determined for both mature green and fresh fully ripe fruits for each plot.

3.3.4.7. Lycopene

The Lycopene content of fruits was determined based on colorimetry upon pigment extraction in petroleum ether method by Ranganna (1976). The mean content was determined for the fruits in each treatment $plot^{-1}$ and was expressed as mg 100 g^{-1} of fresh ripe fruit.

3.3.4.8. Incidence of pests and diseases

Observations were periodically taken for the incidence of physiological disorders like fruit cracking and incidence of pests and diseases. The net plot plants were observed for the purpose. Fruit cracking percentage was determined by finding out the ratio of number of cracked fruits $harvest^{-1}$ to the total number of fruits obtained $harvest^{-1}$, expressed in percentage. The mean values were recorded for each treatment. The percentage pest infestation and disease incidences were also determined in the same manner.

3.3.5. Soil analysis

Soil was analyzed for chemical properties before and after the experiment by obtaining composite samples from the top 15 cm layer of soil. The samples obtained were air dried in shade, sieved with 2 mm sieve for N, P and K analysis and sieved with 0.5 mm sieve for determining organic carbon content.

3.3.5.1. Organic carbon content

The soil organic carbon content after the experiment was expressed in percentage. It was estimated using Walkley and Black's rapid titration method (Jackson, 1973).

3.3.5.2. Available nitrogen content

The available N content of soil after the experiment was estimated using alkaline permanganate method (Subbiah and Asija, 1956) and expressed in kilogram hectare^{-1} (kg ha^{-1}).

3.3.5.3. Available phosphorus content

The available P_2O_5 content in soil after the experiment was estimated using Dickman and Brays molybdenum blue method using Bray No.1 reagent for extraction (Jackson, 1973) and expressed in kilogram hectare^{-1} (kg ha^{-1}).

3.3.5.4. Available potassium content

The available K_2O content in soil after the experiment was determined using neutral ammonium acetate extract and estimated using EEL Flame photometer (Jackson, 1973) and expressed in kilogram hectare^{-1} (kg ha^{-1}).

3.3.6. Plant analysis

The plant samples were subjected to chemical analysis for determining the total N, P, and K content in them. For this purpose, plant samples from each plot were dried in an electric hot air oven to constant weights at a temperature of 70^{0}C, ground and passed through a 0.5 mm sieve. The required quantity of sample was

Plate 1. General view of the experimental field at different stages (Tomato)

Plate 2. General view of the experimental field (Amaranthus)

weighed out accurately in an electronic balance, subjected to acid extraction before carrying out the chemical analysis.

3.3.7. Uptake of nutrients

The total uptake of nitrogen, phosphorus and potassium by tomato plants was calculated as the product of nutrient content and the respective plant dry weight. It was expressed in kg ha^{-1}.

3.3.8. Economics of cultivation

For economic analysis, the benefit-cost ratio was computed based on the cost of cultivation and prevailing price of the crop produce.

$$\text{Benefit - cost ratio} = \frac{\text{Gross income}}{\text{Gross expenditure}}$$

3.3.9. Statistical analysis

The data generated were subjected to analysis of variance (Panse and Sukhatme, 1967). Wherever the result was significant, the critical difference was worked out at 1% and 5 % probabilities. Main effects and the interaction effects were thoroughly studied and interpreted when they became significant.

3.4. Residual crop – Amaranthus

After harvest of tomato crop, the treatment plots were thoroughly ploughed and levelled after uprooting the crop stumps. Seeds of amaranthus (*Amaranthus tricolor*) were sown at a spacing of 25 cm x 25 cm in the levelled plots. The plots were given uniform irrigation frequently. After the emergence of seedlings, the seedlings were thinned during the 2nd week of sowing by keeping only one plant at each position. A total of 69 plants were maintained in each plot. There was no serious disease or pest incidence in the crop's tenure. The crop was harvested at 40 DAS before flowering.

3.4.1. Observations

3.4.1.1. Growth characters

Biometric observations including plant height, number of leaves and LAI were assessed at 35 DAS and the DMP after the harvest of the crop. Five plants were selected at random in each plot excluding the border rows for the observation.

3.4.1.2. Yield

The marketable yield (excluding root) of amaranthus from all the treatment plots was determined from the plants excluding the border rows. The marketable yield from each plot converted to $hectare^{-1}$ yield being expressed in $t\ ha^{-1}$.

3.4.1.3. Plant analysis

The plant samples from each treatment were subjected to chemical analysis for determining the total N, P and K content.

3.4.1.4. Uptake of nutrients

3.4.1.5. Economics of cultivation

3.4.1.6. Statistical analysis

RESULTS

4. RESULTS

A field experiment was conducted at the Instructional Farm attached to the College of Agriculture, Vellayani during the year 2009 – 2010 to study the effects of organic nutrition and spacing and their interaction upon growth, yield, quality and nutrient uptake of tomato and to assess the residual effect of organic nutrition on the succeeding crop. The economics of organic tomato production was also worked out. The results of the study are presented herein.

4.1. Growth characters (Table 4.1)

The major growth characters recorded include plant height, leaves plant^{-1}, branches plant^{-1}, secondary branches plant^{-1} and leaf area index (LAI). All these observations were recorded at the initial stage ie, 2 weeks after transplanting (WAT), the flowering stage (FS) and the harvesting stage (HS) of plant growth.

4.1.1. Plant height (cm)

The effect of nutrient levels and spacing were significant throughout the growth stages with the tallest plants in N_4 (75.71, 84.58 and 111.51 respectively) followed by N_1 (49.96, 71.78 and 102.56 respectively) and the shortest in N_3 (25.92, 45.32 and 90.01 respectively) following N_2 (32.87, 48.41 and 98.53 respectively). The widest spaced plants (S_1) produced the tallest plants (51.08, 71.50 and 113.75 respectively) followed by the wider spaced (S_2) (45.61, 65.18 and 100.94 respectively) and the closely spaced (S_3), the shortest (41.66, 50.89 and 87.27 respectively).

The interaction effects were significant only at the flowering stage with the tallest plants in N_4S_1 (96.23) followed by N_4S_2 (92.20) and were on par with each other and superior to all other treatments.

4.1.2. Leaves plant^{-1}

The effect of nutrient levels and spacing were significant throughout the growth stages with the highest leaf number in N_4 (13.56, 24.99 and 43.83

respectively) followed by N_1 and N_3 in the initial stages and in N_1 at the flowering and harvest stages of the crop. The leaf production was the lowest in N_2 at the first two stages (8.53 and 17.12 respectively) and in N_3 at the harvest stage (29.13). The widest spaced plants (S_1) produced maximum leaves (11.51, 21.59 and 42.08 respectively) followed by the wider spaced (S_2), and the closely spaced (S_3), the lowest (9.48, 18.35 and 32.35 respectively).

The interaction effects were significant at the initial two stages with the highest leaf number in N_4S_1 (15.40 and 27.38 respectively) followed by N_4S_2 (13.53 and 24.23 respectively). The leaf production was the lowest in N_2S_3 in the initial stage (7.76) and in N_3S_3 at the flowering stage (15.16).

4.1.3. Branches plant^{-1}

The effect of nutrient levels and spacing were significant throughout the growth stages with the highest branching in N_4 (3.17, 4.61 and 5.53 respectively) and was found on par with N_3 at the harvest stage (5.44). The branching effect was the lowest in N_1 at the initial and the harvest stages (0.17 and 4.51 respectively) and in N_3 at the flowering stage (3.68). Branching in N_2 (4.73) at the harvest stage was found on par with N_1 (4.51). The widest spaced plants (S_1) branched the most (2.80, 5.20 and 6.22 respectively) followed by the wider spaced (S_2), and the closely spaced (S_3), the least (0.95, 2.54, and 3.52 respectively).

The interaction effects were significant at the first two stages with the highest branching in N_2S_1 (3.8 and 5.5 respectively) followed by N_4S_1 (3.57 and 5.50 respectively) and branching was not initiated in N_1S_3 at the initial stage. At the flowering stage, the branching was the lowest in N_3S_3 (1.43).

4.1.4. Secondary branches plant^{-1}

The effect of nutrient levels and spacing were significant throughout the growth stages with the highest secondary branching in N_4 (0.67, 1.67 and 2.09 respectively) and was on par with N_3 (1.92) at the harvest stage. Even though N_1 did not produce any secondary branches at the initial stage, towards the harvest

Table 4.1 Effect of nutrient levels and spacing on growth characters.

Treatments	Plant height (cm)			Number of leaves			Number of branches			Number of secondary branches			Leaf Area Index (LAI)		
	2 WAT	FS	HS	2 WAT	FS	HS	2 WAT	FS	HS	2 WAT	FS	HS	2 WAT	FS	HS
Nutrient levels (N)															
N_1	49.96	71.78	102.56	10.06	20.20	40.43	0.17	4.07	4.51	0.00	1.24	1.50	0.187	0.579	1.394
N_2	32.87	48.41	98.53	8.53	17.12	35.40	2.50	3.97	4.73	0.44	1.10	1.61	0.133	0.373	1.073
N_3	25.92	45.32	90.01	9.94	17.39	29.13	2.29	3.68	5.44	0.33	0.99	1.92	0.150	0.314	0.691
N_4	75.71	84.58	111.51	13.56	24.99	43.83	3.17	4.61	5.53	0.67	1.67	2.09	0.337	0.977	2.023
S.E.	0.575	1.13	1.176	0.17	0.17	0.57	4.666	0.053	0.075	0.055	0.129	0.061	0.015	0.016	0.024
C.D(0.05)	1.686	3.316	3.45	0.498	0.498	1.673	0.137	0.157	0.221	0.163	0.379	0.181	0.044	0.047	0.071
Spacing (S)															
S_1	51.08	71.50	113.75	11.51	21.59	42.08	2.80	5.20	6.22	0.75	2.24	2.55	0.188	0.536	1.295
S_2	45.61	65.18	100.94	10.57	19.83	37.16	2.33	4.50	5.42	0.33	1.34	1.92	0.179	0.513	1.280
S_3	41.66	50.89	87.27	9.48	18.35	32.35	0.95	2.54	3.52	0.00	0.17	0.87	0.238	0.634	1.310
S.E.	0.498	0.979	1.019	0.147	0.147	0.494	0.04	0.046	0.065	0.048	0.112	0.053	0.013	0.014	0.021
C.D(0.05)	1.46	2.871	2.988	0.432	0.431	1.449	0.118	0.136	0.191	0.141	0.328	0.157	0.038	0.041	NS
Nutrient levels (N) x Spacing (S)															
N_1S_1	54.06	78.67	118.37	10.88	21.47	45.63	0.40	4.67	5.60	0.00	2.33	2.73	0.168	0.545	1.441
N_1S_2	49.77	72.98	101.83	10.07	20.10	40.53	0.10	4.40	4.43	0.00	1.40	1.77	0.174	0.528	1.292
N_1S_3	46.05	63.68	87.47	9.23	19.03	35.13	0.00	3.13	3.50	0.00	0.00	0.00	0.218	0.665	1.449
N_2S_1	36.13	55.75	110.33	9.23	18.30	40.50	3.80	5.50	6.23	1.00	2.17	2.40	0.135	0.427	1.106
N_2S_2	32.98	47.84	102.83	8.60	17.20	35.67	3.10	4.47	4.57	0.33	1.13	1.37	0.120	0.309	1.190
N_2S_3	29.51	41.65	82.43	7.76	15.87	30.03	0.60	1.93	3.40	0.00	0.00	1.07	0.143	0.382	0.922
N_3S_1	32.46	55.37	101.02	10.53	19.20	33.73	3.47	5.13	6.50	1.00	2.03	2.37	0.154	0.332	0.796
N_3S_2	23.98	47.70	87.15	10.10	17.80	28.97	2.93	4.47	6.33	0.00	0.93	2.20	0.134	0.301	0.747
N_3S_3	21.33	32.90	81.87	9.20	15.16	24.70	0.47	1.43	3.50	0.00	0.00	1.20	0.161	0.310	0.531
N_4S_1	81.66	96.23	125.27	15.40	27.38	48.47	3.57	5.50	6.53	1.00	2.43	2.70	0.296	0.839	1.838
N_4S_2	75.71	92.20	111.97	13.53	24.23	43.47	3.20	4.67	6.37	1.00	1.90	2.33	0.287	0.915	1.892
N_4S_3	69.77	65.31	97.30	11.73	23.37	39.57	2.73	3.67	3.70	0.00	0.67	1.23	0.429	1.178	2.339
S.E.	0.996	1.958	2.037	0.294	0.294	0.988	0.081	0.092	0.131	0.096	0.224	0.107	0.026	0.028	0.042
C.D(0.05)	NS	5.743	NS	0.863	0.863	NS	0.237	0.272	NS	0.282	NS	NS	NS	0.082	0.124

WAT - Weeks after transplanting FS – Flowering stage HS – Harvesting stage NS- Non significant stage, it also produced secondary branches but the lowest (1.50). At the flowering stage secondary branching was the lowest in N_3 (0.99). Secondary branching was the highest in the widest spaced (S_1) plants (0.75, 1.34 and 1.92 respectively) followed by the wider spaced (S_2), and the lowest in the closely spaced (S_3) plants (0, 0.17 and 0.87 respectively).

The interaction effects were significant at the initial stage only. By producing a single secondary branch each, the treatments N_2S_1,N_3S_1,N_4S_1 and N_4S_2 ranked superior to all others followed by N_2S_2 (0.33). Secondary branching was absolutely absent in others.

4.1.5. Leaf Area Index (LAI)

The effect of nutrient levels was significant throughout the growth stages and spacing significant only at the initial and flowering stages of the plant. LAI was the highest in N_4 (0.337, 0.977 and 2.023 respectively) followed by N_1 and the lowest in N_2 (0.13) at the initial stage and in N_3 at the other two stages (0.314 and 0.691 respectively). The closely spaced plants (S_3) recorded the highest LAI (0.238 and 0.634 respectively) followed by the widest (S_1) and wider spaced (S_2) and were on par with each other (0.188, 0.536 and 0.179, 0.513 respectively).

The interaction effects were significant at the flowering and harvesting stages with the highest LAI in N_4S_3 (1.178 and 2.339 respectively) followed by N_4S_2 (0.915 and 1.892 respectively) and N_4S_1 (0.839 and 1.838 respectively) which were on par with each other and the lowest in N_3S_2 (0.301) at the flowering stage and in N_3S_3 at the harvesting stage (0.531).

4.2. Observations on flowering and flower characters (Table 4.2)

4.2.1 Days to first flowering

The effect of nutrient levels and spacing were significant with early flowering in N_3 (47 days), followed by N_4 (49.89 days) and N_1 (50.11 days) which were on par and late in N_2 (51.22 days) . Early flowering (47 days) was noticed in closely spaced plants (S_3), followed by the widest (S_1) spaced (49.92 days) and the wider (S_2) spaced plants (51.75 days).

4.2.2. Flowering intensity (%)

The observation on flowering intensities was recorded at 45, 55, 65 and 75 DAS. All plants bore flowers at 75 DAS irrespective of the treatments.

The effect of nutrient levels was significant at 45, 55 and 65 DAS and spacing effect significant only at 45 and 55 DAS. The flowering intensity was the highest in N_3 (12.44) at 45 DAS which was on par with N_2 (11.44) and in N_1 (50.54) at 55 DAS and in N_4 (95.08) at 65 DAS even though N_4 did not flower initially. The flowering intensity was the highest in closely (S_3) spaced plants (11.67 and 56.51 respectively) followed by the widest (S_1) spaced (10.55) at 45 DAS and the wider (S_2) spaced (40.02) at 55 DAS. Plants did not flower in the wider spaced plants (S_2) at 45 DAS and at 55 DAS flowering was the lowest in the widest (S_1) spaced plants (33.26).

4.2.3. Flowers plant^{-1}

The observation on number of flowers was taken at 45, 55, 65 and 75 DAS. The observation at 75 DAS was taken for granted as the average number of flowers plant^{-1}.

The effect of nutrient levels and spacing were significant at 75 DAS with the highest flower production in N_4 (24.20) followed by N_1 (19.91), N_2 (15.98) and N_3 (15.81) and were on par with each other. The number of flowers plant^{-1} was the highest in closely spaced (S_3) plants (20.90) followed by the wider (S_2) spaced (18.60) and the lowest in the widest spaced (S_1) plants (17.42).

The interaction effects were significant at all the stages with the highest flower production in N_4S_3 (27.83) followed by N_4S_2 (22.96) and the lowest in N_2S_1 (13.66).

Table 4.2. Effect of nutrient levels and spacing on flowering and flower characters

Treatments	Flowering intensity (%)				Number of flowers plant^{-1}				Days to first flowering	Number of flowers bunch^{-1}	Number of flowering bunches plant^{-1}
	45 DAS	55 DAS	65 DAS	75 DAS	45 DAS	55 DAS	65 DAS	75 DAS			
Nutrient levels (N)											
N_1	5.74	50.54	78.65	100	1.08	10.16	14.68	19.91	50.11	3.66	5.78
N_2	11.44	34.14	66.79	100	2.57	5.20	12.69	15.98	51.22	3.46	5.26
N_3	12.44	41.67	67.24	100	2.46	6.39	12.14	15.81	47.00	3.69	4.43
N_4	0.00	46.71	95.08	100	0.00	13.17	19.10	24.20	49.89	4.91	5.33
S.E.	0.492	0.832	1.124	0.000	0.139	0.315	0.358	0.110	0.342	0.090	0.111
C.D (0.05)	1.443	2.441	3.297	NS	0.407	0.925	1.049	0.323	1.002	0.266	0.326
Spacing (S)											
S_1	10.55	33.26	74.75	100	1.78	7.12	11.61	17.42	49.92	4.36	4.64
S_2	0.00	40.02	78.32	100	0.00	6.95	14.88	18.60	51.75	4.18	4.54
S_3	11.67	56.51	77.75	100	2.79	12.11	17.47	20.90	47.00	3.24	6.42
S.E.	0.426	0.721	0.973	0.000	0.120	0.273	0.310	0.095	0.296	0.078	0.096
C.D (0.05)	1.250	2.114	NS	NS	0.352	0.801	0.908	0.279	0.868	0.231	0.282
Nutrient levels (N) x Spacing (S)											
N_1S_1	17.21	55.43	69.15	100	3.23	9.10	16.13	18.87	44.67	3.17	6.57
N_1S_2	0.00	23.10	80.90	100	0.00	7.40	12.63	19.53	54.00	4.47	4.37
N_1S_3	0.00	73.10	85.90	100	0.00	13.97	15.27	21.33	51.67	3.33	6.40
N_2S_1	0.00	0.00	53.13	100	0.00	0.00	6.53	13.66	58.67	4.80	3.50
N_2S_2	0.00	56.33	78.73	100	0.00	4.37	14.27	15.37	51.00	2.77	5.50
N_2S_3	34.33	46.10	68.50	100	7.70	11.23	17.27	18.90	44.00	2.80	6.77
N_3S_1	25.00	49.96	83.15	100	3.90	7.53	11.03	15.37	42.67	3.70	4.20
N_3S_2	0.00	28.77	53.63	100	0.00	2.17	12.87	16.53	54.33	4.43	3.77
N_3S_3	12.33	46.28	64.93	100	3.47	9.47	12.53	15.53	44.00	2.93	5.33
N_4S_1	0.00	27.64	93.57	100	0.00	11.87	12.73	21.80	53.67	5.77	4.30
N_4S_2	0.00	51.90	100.00	100	0.00	13.87	19.77	22.96	47.67	5.07	4.53
N_4S_3	0.00	60.58	91.66	100	0.00	13.77	24.80	27.83	48.33	3.90	7.17
S.E.	0.852	1.441	1.947	0.000	0.240	0.546	0.619	0.191	0.592	0.157	0.192
C.D (0.05)	2.499	4.228	5.712	NS	0.704	1.602	1.817	0.559	1.735	0.461	0.564

DAS - Days after sowing.

4.2.4. Flowering branches (bunches) plant^{-1}

The effect of nutrient levels and spacing were significant with the highest flowering branches in N_1 (5.78) followed by N_4 (5.33) and N_2 (5.26), which were on par with each other and the lowest in N_3 (4.43). The closely spaced plants (S_3) produced the highest number of flowering branches (6.42) and were significantly superior to the widest (S_1) and wider spaced (S_2) plants (4.64 and 4.54 respectively).

The interaction effects were significant with the highest number of flowering branches in N_4S_3, N_2S_3, N_1S_1 and N_1S_3 which were on par and the lowest in N_3S_2 and N_2S_1 and were inferior to all others.

4.2.5. Flowers bunch^{-1}

The effect of nutrient levels and spacing were significant with the highest number of flowers bunch^{-1} in N_4 (4.91). All others were on par with each other and the lowest in N_2 (3.46). The flower production bunch^{-1} was the highest in the widest spaced (S_1) plants (4.36) followed by the wider spaced (S_2) which were on par and the lowest in closely spaced (S_3) plants (3.24).

The interaction effects were significant with N_4S_1 producing the highest number of flowers bunch^{-1} (5.77) followed by N_4S_2 (5.07) and N_2S_1 (4.80) which were on par with each other and the lowest in N_2S_2 (2.77).

4.3. Observations on fruiting and fruit characters (Table 4.3)

4.3.1 Fruiting Intensity (%)

The observation on fruiting intensity was recorded at 60, 70, 75 and 90 DAS. An important fact is that all plants bore fruits (cent percent fruiting) at 90 DAS irrespective of the treatments.

The effect of nutrient levels was significant at 60, 70 and 75 DAS and spacing at 60 and 70 DAS only. The fruiting intensity was the highest in N_1

Table 4.3. Effect of nutrient levels and spacing on fruiting and fruit characters

Treatments	Fruiting intensity (%)				Number of fruits plant^{-1}	Number of fruits bunch^{-1}	Fruit set (%)	Days to fruit maturity after setting	Days to first harvest	Number of harvests
	60 DAS	70 DAS	75 DAS	90 DAS						
Nutrient levels (N)										
N_1	20.57	38.56	67.30	100	17.97	3.23	87.54	30.74	95.89	5.78
N_2	7.66	11.74	40.17	100	14.10	2.98	83.92	30.27	97.56	4.33
N_3	10.83	28.25	60.59	100	11.43	2.68	71.43	28.97	95.11	5.67
N_4	9.57	31.40	57.53	100	21.41	4.30	85.68	32.39	96.11	6.78
S.E.	0.484	0.703	0.756	0.000	0.106	0.084	0.661	0.241	0.080	0.080
C.D (0.05)	1.419	2.063	2.217	NS	0.311	0.245	1.939	0.707	0.236	0.236
Spacing (S)										
S_1	13.46	25.90	55.73	100	18.21	4.07	92.85	33.62	98.75	5.25
S_2	3.93	21.06	55.57	100	16.73	3.73	89.72	30.04	96.75	5.58
S_3	19.07	35.50	57.89	100	13.74	2.09	63.87	28.12	93.00	6.08
S.E.	0.419	0.609	0.655	0.000	0.092	0.072	0.573	0.198	0.209	0.070
C.D (0.05)	1.229	1.787	NS	NS	0.269	0.212	1.680	0.582	0.612	0.204
Nutrient levels (N) x Spacing (S)										
N_1S_1	29.17	43.67	66.37	100	19.60	2.97	93.67	31.53	96.33	6.00
N_1S_2	0.00	30.13	63.17	100	18.77	4.33	97.01	30.70	96.00	5.33
N_1S_3	32.53	41.87	72.37	100	15.53	2.40	71.95	30.00	95.33	6.00
N_2S_1	0.00	0.00	49.53	100	16.23	4.60	95.87	32.67	101.33	3.00
N_2S_2	0.00	0.00	30.33	100	14.63	2.67	96.38	29.07	99.33	4.00
N_2S_3	22.97	35.23	40.63	100	11.43	1.67	59.52	29.07	92.00	6.00
N_3S_1	11.70	34.92	64.32	100	13.40	3.20	86.52	32.60	96.00	6.00
N_3S_2	0.00	18.37	64.68	100	12.00	3.20	72.06	29.13	97.67	6.00
N_3S_3	20.80	31.47	52.77	100	8.90	1.63	55.71	25.20	91.67	5.00
N_4S_1	12.99	25.03	42.70	100	23.60	5.50	95.32	37.70	101.33	6.00
N_4S_2	15.72	35.73	64.10	100	21.53	4.73	93.44	31.27	94.00	7.00
N_4S_3	0.00	33.43	65.80	100	19.10	2.66	68.29	28.20	93.00	7.33
S.E.	0.838	1.218	1.309	0.000	0.184	0.145	1.145	0.397	0.417	0.139
C.D (0.05)	2.459	3.574	3.840	NS	NS	0.424	3.359	1.164	1.224	0.408

DAS - Days after sowing

(67.30) followed by N_3 (60.59) and N_4 (57.53) and the lowest in N_2 (40.16) at 75 DAS. The closely spaced (S_3) plants recorded the highest fruiting intensities at 60 DAS (19.07) and 70 DAS (35.50) and the wider spaced (S_2), the lowest (3.93 and 21.06 respectively).

The interaction effects were significant at 60, 70 and 75 DAS with N_4S_3 recording the highest fruiting intensity at 75 DAS (65.80).

4.3.2. Number of fruits plant^{-1} (90 DAS)

The effect of nutrient levels and spacing were significant with the highest number of fruits in N_4 (21.41) followed by N_1 (17.97) and the lowest in N_3 (11.43). All the treatments were significantly different from one another. The fruit production plant^{-1} was the highest (18.21) in the widest spaced plants (S_1) followed by the wider spaced (S_2) and the lowest in the closely spaced (S_3) plants (13.74).

The interaction effects were not significant.

4.3.3. Number of fruits bunch^{-1}

The effect of nutrient levels and spacing were significant with the highest number of fruits bunch^{-1} in N_4 (4.30) followed by N_1 (3.23) and N_2 (2.98) and the lowest in N_3 (2.68). The bunch^{-1} fruit production was the highest in the widest spaced (S_1) plants (4.07) followed by the wider spaced (S_2) and the closely spaced (S_3), the lowest (2.09).

The interaction effects were significant with the highest number of fruits bunch^{-1} in N_4S_1 (5.50) followed by N_4S_2 (4.73), N_2S_1 (4.6) and N_1S_2 (4.33) and the lowest in N_2S_3 (1.67) and N_3S_3 (1.63).

4.3.4. Percentage fruit setting from flowers (%)

The effect of nutrient levels and spacing were significant with the highest fruit set in N_1 (87.54) followed by N_4 (85.68) and N_2 (83.92) which were on par with each other and the lowest in N_3 (71.43). The widest spaced plants (S_1) gave

Table 4.3. Effect of nutrient levels and spacing on fruiting and fruit characters

Treatments	Fruiting intensity (%)				Number of fruits plant^{-1}	Number of fruits bunch^{-1}	Fruit set (%)	Days to fruit maturity after setting	Days to first harvest	Number of harvests
	60 DAS	70 DAS	75 DAS	90 DAS						
Nutrient levels (N)										
N_1	20.57	38.56	67.30	100	17.97	3.23	87.54	30.74	95.89	5.78
N_2	7.66	11.74	40.17	100	14.10	2.98	83.92	30.27	97.56	4.33
N_3	10.83	28.25	60.59	100	11.43	2.68	71.43	28.97	95.11	5.67
N_4	9.57	31.40	57.53	100	21.41	4.30	85.68	32.39	96.11	6.78
S.E.	0.484	0.703	0.756	0.000	0.106	0.084	0.661	0.241	0.080	0.080
C.D (0.05)	1.419	2.063	2.217	NS	0.311	0.245	1.939	0.707	0.236	0.236
Spacing (S)										
S_1	13.46	25.90	55.73	100	18.21	4.07	92.85	33.62	98.75	5.25
S_2	3.93	21.06	55.57	100	16.73	3.73	89.72	30.04	96.75	5.58
S_3	19.07	35.50	57.89	100	13.74	2.09	63.87	28.12	93.00	6.08
S.E.	0.419	0.609	0.655	0.000	0.092	0.072	0.573	0.198	0.209	0.070
C.D (0.05)	1.229	1.787	NS	NS	0.269	0.212	1.680	0.582	0.612	0.204
Nutrient levels (N) x Spacing (S)										
N_1S_1	29.17	43.67	66.37	100	19.60	2.97	93.67	31.53	96.33	6.00
N_1S_2	0.00	30.13	63.17	100	18.77	4.33	97.01	30.70	96.00	5.33
N_1S_3	32.53	41.87	72.37	100	15.53	2.40	71.95	30.00	95.33	6.00
N_2S_1	0.00	0.00	49.53	100	16.23	4.60	95.87	32.67	101.33	3.00
N_2S_2	0.00	0.00	30.33	100	14.63	2.67	96.38	29.07	99.33	4.00
N_2S_3	22.97	35.23	40.63	100	11.43	1.67	59.52	29.07	92.00	6.00
N_3S_1	11.70	34.92	64.32	100	13.40	3.20	86.52	32.60	96.00	6.00
N_3S_2	0.00	18.37	64.68	100	12.00	3.20	72.06	29.13	97.67	6.00
N_3S_3	20.80	31.47	52.77	100	8.90	1.63	55.71	25.20	91.67	5.00
N_4S_1	12.99	25.03	42.70	100	23.60	5.50	95.32	37.70	101.33	6.00
N_4S_2	15.72	35.73	64.10	100	21.53	4.73	93.44	31.27	94.00	7.00
N_4S_3	0.00	33.43	65.80	100	19.10	2.66	68.29	28.20	93.00	7.33
S.E.	0.838	1.218	1.309	0.000	0.184	0.145	1.145	0.397	0.417	0.139
C.D (0.05)	2.459	3.574	3.840	NS	NS	0.424	3.359	1.164	1.224	0.408

DAS - Days after sowing

the highest fruit set (92.85) followed by the wider spaced (S_2) (89.72) and the closely spaced (S_3), the lowest (63.87).

The interaction effects were significant with the highest fruit set in N_1S_2 (97.01) followed by N_2S_2, N_2S_1, N_4S_1, N_1S_1 and N_4S_2 and all were on par and superior to others and the lowest in N_3S_3 (55.71).

4.3.5. Days to maturity after fruit setting

The effect of nutrient levels and spacing were significant with early maturity of fruits in N_3 (28.97 days) followed by N_2 (30.27 days) and N_1 (30.74 days) and late in N_4 (32.39 days). Early maturity (28.12 days) of fruits in the closely spaced plants (S_3) followed by wider spaced (S_2) and late in the widest spaced (S_1) plants (33.62 days).

The interaction effects were significant with early maturity in N_3S_3 (25.20 days) followed by N_3S_1 (32.60 days) and N_2S_1 (32.67 days) and late in N_4S_1 (37.70 days).

4.3.6. Days to first harvest

The effect of nutrient levels and spacing were significant with early harvesting in N_3 (95.11 days) followed by N_1 (95.89 days) and N_4 (96.11 days) and late in N_2 (97.56 days). Early harvesting of fruits in closely spaced (S_3) plants (93.04 days) followed by the wider spaced (S_2) and late in the widest spaced (S_1) plants (98.75 days).

The interaction effects were significant with early harvesting in N_3S_3 (91.67 days) followed by N_2S_2 (99.33 days) and late in N_2S_1 and N_4S_1 (101.33 days each respectively).

4.3.7. Number of harvests

The effect of nutrient levels and spacing were significant with minimum number of harvests in N_2 (4.33) followed by N_3 (5.67) and N_1 (5.78) and maximum in N_4 (6.78).

The interaction effects were significant with minimum number of harvests in N_2S_1 (3) followed by N_2S_2 (4) and maximum in N_4S_3 (7.33) and N_4S_2 (7.00).

4.4. Observations on yield & yield characters (Table 4.4)

4.4.1. Fruit yield plant^{-1} (g plant^{-1})

The effect of nutrient levels and spacing were significant with the highest fruit yield in N_4 (557.47) followed by N_1 (387.13) and N_2 (285.75) and the lowest in N_3 (214.89). The fruit yield was the highest in the widest spaced (S_1) plants (425.54) followed by the wider spaced (S_2), and the lowest in the closely spaced (S_3) plants (289.97).

The interaction effects were significant with the highest fruit yield in N_4S_1 (663.19) followed by N_4S_2 (555.88) and the lowest in N_3S_3 (159.34) and was significantly lower than all other treatments.

4.4.2. Fruit yield hectare^{-1} (t ha^{-1})

The effect of nutrient levels and spacing were significant with the highest yield in N_4 (27.75) followed by N_1 (17.18) and N_2 (12.92) and the lowest in N_3 (9.61). The closely spaced plants (S_3) gave the highest yield (18.40) followed by the wider spaced (S_2) (16.48) and the widest spaced (S_1), the lowest (15.71).

The interaction effects were significant with the highest yield in N_4S_3 (32.32) followed by N_4S_2 (26.29) and N_4S_1 (24.64) and the lowest in N_3S_1 (8.91).

4.4.3. Average fruit weight (g)

The effect of nutrient levels and spacing were significant with the heaviest fruits in N_4 (25.88) followed by N_1 (21.49) and N_2 (20.19) and the lightest in N_3 (18.69). The widest spaced plants (S_1) produced the heaviest fruits (22.72) followed by the wider (S_2) spaced (21.47) and the closely spaced (S_3), the lightest (20.51).

Table 4.4. Effect of nutrient levels and spacing on fruit yield and quality

Treatments	Fruit yield (g plant^{-1})	Fruit yield (t ha^{-1})	Average fruit weight (g)	Average fruit girth (cm)	Days to colour change of fruits from yellow to red
Nutrient levels (N)					
N_1	387.13	17.18	21.49	11.56	6.68
N_2	285.75	12.92	20.19	11.49	5.42
N_3	214.89	9.61	18.69	11.08	4.66
N_4	557.47	27.75	25.88	12.92	5.39
S.E.	3.048	0.145	0.085	0.026	0.058
C.D (0.05)	8.939	0.424	0.251	0.077	0.169
Spacing (S)					
S_1	425.54	15.71	22.72	12.20	5.60
S_2	368.42	16.48	21.47	11.76	4.81
S_3	289.97	18.40	20.51	11.33	6.20
S.E.	2.639	0.125	0.074	0.023	0.050
C.D (0.05)	7.741	0.368	0.217	0.067	0.146
Nutrient levels (N) x Spacing (S)					
N_1S_1	438.94	16.75	22.39	12.09	6.67
N_1S_2	398.64	16.95	21.24	11.52	5.30
N_1S_3	323.81	17.85	20.85	11.08	8.07
N_2S_1	337.97	12.56	20.82	11.82	6.10
N_2S_2	295.90	12.84	20.22	11.57	5.03
N_2S_3	223.38	13.35	19.54	11.09	5.13
N_3S_1	262.04	8.91	19.55	11.39	4.40
N_3S_2	223.28	9.84	18.61	11.27	4.33
N_3S_3	159.34	10.07	17.91	10.58	5.23
N_4S_1	663.19	24.64	28.10	13.48	5.23
N_4S_2	555.88	26.29	25.82	12.68	4.57
N_4S_3	453.35	32.32	23.74	12.58	6.37
S.E.	5.279	0.251	0.148	0.045	0.099
C.D (0.05)	15.482	0.735	0.435	0.133	0.293

The interaction effects were significant with the heaviest fruits in N_4S_1 (28.10) followed by N_4S_2 (25.82) and N_4S_3 (23.74) and the lightest in N_3S_3 (17.91).

4.4.4. Average fruit size (fruit girth in cm)

The effect of nutrient levels and spacing were significant with the largest plump fruits in N_4 (12.92) followed by N_1 (11.56) and N_2 (11.49) which were on par with each other and the smallest in N_3 (11.08). The widest spaced (S_1) plants produced plump fruits (12.20) followed by the wider spaced (S_2) (11.76) and the closely spaced (S_3), the smallest (11.33).

The interaction effects were significant with N_4S_1 producing plump fruits with an average girth of 13.48 cm followed by N_4S_2 (12.68) and N_4S_3 (12.58). The treatments N_1S_1 and N_2S_1 followed next with average fruit girth of 12.09 cm and 11.82 cm respectively and the smallest fruits were in N_3S_3 (10.58).

4.4.5. Days to colour change of fruits from yellow to red

The effect of nutrient levels and spacing were significant with a slow change in colour in N_1 (6.68 days) followed by N_2 (5.42 days) and N_4 (5.39 days) and fast in N_3 (4.66 days). The colour change was slow in the closely spaced plants (S_3) followed by the widest spaced (S_1) (5.60 days) and fast in the wider spaced (S_2) plants (4.81 days).

The interaction effects were significant with a slow colour change in N_1S_3 (8.07 days) followed by N_1S_1 (6.67 days) and fast in N_3S_2 (4.33 days) followed by N_3S_1 (4.40 days) and N_4S_2 (4.57 days).

4.5. Shelf life of fruits (days) (Table 4.5)

4.5.1. In open air

The effect of nutrient levels and spacing were significant with the longest storage period in N_2 (8.05) followed by N_1 (6.65) and N_3 (6.04) and the shortest in N_4 (4.35). The shelf life of fruits was the longest in closely spaced (S_3) plants

Table 4.5. Effect of nutrient levels and spacing on shelf life of fruits (days)

Treatments	Open air (days)	30 micron plastic cover (days)	Paper cover (days)
Nutrient levels (N)			
N_1	6.65	9.82	13.77
N_2	8.05	9.48	12.39
N_3	6.04	9.29	12.54
N_4	4.35	9.45	13.94
S.E.	0.076	0.049	0.085
C.D (0.05)	0.223	0.144	0.249
Spacing (S)			
S_1	5.26	7.12	11.75
S_2	5.73	10.25	14.01
S_3	7.82	11.16	13.72
S.E.	0.067	0.043	0.073
C.D (0.05)	0.193	0.125	0.215
Nutrient levels (N) x Spacing (S)			
N_1S_1	4.62	6.49	11.82
N_1S_2	6.17	10.61	14.20
N_1S_3	9.17	12.36	15.30
N_2S_1	7.66	9.06	11.20
N_2S_2	7.60	9.22	14.51
N_2S_3	8.88	10.16	11.47
N_3S_1	4.51	5.65	10.52
N_3S_2	5.03	10.78	13.49
N_3S_3	8.57	11.44	13.61
N_4S_1	4.25	7.28	13.48
N_4S_2	4.12	10.41	13.84
N_4S_3	4.68	10.67	14.51
S.E.	0.131	0.085	0.147
C.D (0.05)	0.386	0.250	0.431

(7.82) followed by the wider spaced (S_2) and the shortest in the widest spaced (S_1) plants (5.26).

The interaction effects were significant with the longest storage periods in N_1S_3 (9.17) and N_2S_3 (8.88) which were on par, followed by N_3S_3 (8.57) and the shortest in N_4S_2 (4.12), followed by N_4S_1 (4.25).

4.5.2. In 30 micron plastic cover

The effect of nutrient levels and spacing were significant with the longest storage period in N_1 (9.82) followed by N_2 (9.48) and N_4 (9.45) and the shortest in N_3 (9.29). The shelf life of fruits was the longest in closely spaced (S_3) plants (11.16) followed by the wider spaced (S_2) and the shortest in the widest spaced (S_1) plants (7.12).

The interaction effects were significant with the longest storage period in N_1S_3 (12.36) followed by N_3S_3 (11.44) and the shortest in N_3S_1 (5.65). All other treatments were on par.

4.5.3. In paper cover

The effect of nutrient levels and spacing were significant with the longest storage period in N_4 (13.94) followed by N_1 (13.77) which were on par and the shortest in N_2 (12.39) which was on par with N_3 (12.54). The widely spaced plants (S_2) retained the storage period for long (14.01) compared to the widest spaced, S_1 (11.75) and closely spaced, S_3 (13.72).

The interaction effects were significant with the longest storage period in N_1S_3 (15.30) followed by N_2S_2, N_4S_3 and N_1S_2 respectively which were on par with each other and the shortest in N_3S_1 (10.52).

4.6. Organoleptic tests (Table 4.6)

Organoleptic scoring was not statistically analyzed as the scoring was on whole numbers and clear cut results were obtained in case of each set of treatments. The results obtained varied based on nutrient levels alone.

Table 4.6. Effect of nutrient levels and spacing on organoleptic scores.

Treatments	Taste	Colour	Size
N_1S_1	3	3	2
N_1S_2	3	3	2
N_1S_3	3	3	2
N_2S_1	3	2	2
N_2S_2	3	2	2
N_2S_3	3	2	2
N_3S_1	1	1	1
N_3S_2	1	1	1
N_3S_3	1	1	1
N_4S_1	2	3	3
N_4S_2	2	3	3
N_4S_3	2	3	3

4.6.1. Taste

The fruits were tastier with the highest score in N_1 and N_2 (3 each) followed by N_4 (2) and the lowest score in N_3 (1).

4.6.2. Colour

The fruits were deep red coloured with the highest score in N_1 and N_4 (3 each) followed by N_2 (2) and the lowest score in N_3 (1).

4.6.3. Size

The fruits were plump and large with the highest score in N_4 (3) followed by N_1 and N_2 (2 each) and the lowest in N_3 (1).

4.7. Fruit Quality studies (Table 4.7)

4.7.1. Vitamin C (mg $100g^{-1}$)

The effect of nutrient levels alone was significant with the highest content in N_1 (26.18) followed by N_2 (23.89) and N_3 (20.91) and the lowest in N_4 (19.47).

Plant spacing and interaction effects were not significant.

4.7.2. Total Soluble Solids (TSS)

TSS content of both mature green and fresh ripe fruits were determined and the effect of nutrient levels was significant with the highest TSS content in N_1 at both stages (5.03 and 5.26 respectively) followed by N_4 (4.89 and 5.00 respectively) and the lowest in N_3 (4.19 and 4.49 respectively).

The effect of spacing was not significant.

The interaction effects were significant for mature green fruits only with the highest TSS content in N_1S1 (5.13) and the lowest in N_3S_1 (4.13).

4.7.3. Lycopene (mg 100^{-1} g fruit)

The effect of nutrient levels was significant with the highest content in N_1

Table 4.7. Effect of nutrient levels and spacing on quality characters

Treatments	Vitamin C (mg 100 g^{-1} fruit)	TSS content of mature green fruits (^{0}B)	TSS content of red ripe fruits (^{0}B)	Lycopene (mg 100 g^{-1} fruit)
Nutrient levels (N)				
N_1	26.18	5.03	5.26	7.33
N_2	23.89	4.61	4.87	6.63
N_3	20.91	4.19	4.49	4.64
N_4	19.47	4.89	5.00	7.25
S.E.	0.361	0.021	0.030	0.131
C.D (0.05)	1.058	0.062	0.088	0.384
Spacing (S)				
S_1	22.08	4.69	4.95	6.68
S_2	22.74	4.67	4.89	6.51
S_3	23.02	4.67	4.87	6.20
S.E.	0.312	0.018	0.026	0.113
C.D (0.05)	NS	NS	NS	NS
Nutrient levels (N) x Spacing (S)				
N_1S_1	25.60	5.13	5.30	8.69
N_1S_2	26.12	5.03	5.27	7.25
N_1S_3	26.82	4.93	5.20	6.04
N_2S_1	23.64	4.53	4.90	6.48
N_2S_2	23.31	4.63	4.87	7.06
N_2S_3	24.73	4.67	4.83	6.37
N_3S_1	19.88	4.13	4.53	5.20
N_3S_2	21.99	4.20	4.47	4.70
N_3S_3	20.85	4.23	4.47	4.03
N_4S_1	19.19	4.97	5.07	6.36
N_4S_2	19.53	4.83	4.97	7.05
N_4S_3	19.68	4.87	4.97	8.34
S.E.	0.625	0.036	0.052	0.227
C.D (0.05)	NS	0.108	NS	0.666

(7.33) and N_4 (7.25) which were on par followed by N_2 (6.63) and the lowest in N_3 (4.64).

The effect of spacing was not significant.

The interaction effects were significant with the highest content in N_1S_1 (8.69) followed by N_4S_3 (8.34) which were on par and the lowest in N_3S_3 (4.03).

4.8. Percentage of fruit cracks, pests and diseases (Table 4.8)

4.8.1. Fruit cracking (%)

The effect of nutrient levels and spacing were significant with the lowest fruit cracking in N_4 (2.32) followed by N_2 (5.15) and N_1 (6.53) and the highest in N_3 (14.92). The wider spaced plants (S_2) showed a lower fruit cracking percentage compared to the widest spaced (S_1), and the closely spaced (S_3), the highest (13.05).

The interaction effects were significant without any fruit cracking in N_1S_1, N_2S_1, N_2S_2, N_3S_2, N_4S_1 and N_4S_3 and upto 25.25% in N_3S_3 followed by N_3S_1 (19.49) and N_2S_3 (15.46).

4.8.2. Percentage infestation by fruit borer (%)

The effect of nutrient levels and spacing were significant with the lowest infestation in N_2 (2.64) followed by N_3 (3.32) and N_4 (5.23) and all were on par with each other and the highest in N_1 (8.42) which differed significantly from others. The infestation was the lowest in the widest spaced (S_1) plants (1.37) followed by the wider (S_2) spaced (4.69) and the highest in the closely spaced plants (S_3) plants (8.63).

The interaction effects were significant without any infestation in N_1S_1, N_2S_1, N_3S_1, N_3S_2 and N_4S_3 and up to 16.68 % in N_1S_3.

Table 4.8. Effect of nutrient levels and spacing on fruit cracks, pests and diseases

Treatments	Fruit cracks (%)	Infestation by fruit borer (%)	Infection of Tomato Yellow Leaf Curl Virus (%)
Nutrient levels (N)			
N_1	6.53	8.42	17.72
N_2	5.15	2.64	15.53
N_3	14.92	3.32	13.30
N_4	2.32	5.23	12.23
S.E.	0.583	0.919	0.913
C.D (0.05)	1.710	2.695	NS
Spacing (S)			
S_1	4.87	1.37	12.55
S_2	3.76	4.69	10.47
S_3	13.05	8.63	21.08
S.E.	0.505	0.796	0.791
C.D (0.05)	1.481	2.334	2.320
Nutrient levels (N) x Spacing (S)			
N_1S_1	0.00	0.00	9.60
N_1S_2	8.10	8.59	15.30
N_1S_3	11.50	16.68	28.27
N_2S_1	0.00	0.00	12.43
N_2S_2	0.00	0.00	14.87
N_2S_3	15.46	7.91	19.30
N_3S_1	19.49	0.00	19.22
N_3S_2	0.00	0.00	0.00
N_3S_3	25.25	9.96	20.69
N_4S_1	0.00	5.50	8.93
N_4S_2	6.96	10.19	11.70
N_4S_3	0.00	0.00	16.07
S.E.	1.01	1.592	1.582
C.D (0.05)	2.962	4.668	4.641

4.8.3. Percentage infection by Tomato Yellow Leaf Curl Virus (TYLCV) (%)

The effect of spacing was only significant where the closely spaced plants (S_3) were affected the most (21.08) followed by the widest, S_1 (12.55) and the widely spaced, S_2 (10.47).

The interaction effects were significant without any infestation in N_3S_2, whereas all others were found infected with the highest infection in N_1S_3 (28.27).

4.9. Total crop duration (days) (Table 4.9)

The effect of nutrient levels and spacing were significant and crop duration was the shortest in N_3 (107.44) followed by N_4 (109.33) and N_1 (111.44) and the longest in N_2 (112.22). The widest spaced plants (S_1) were in the field for a shorter period (108.58) followed by the closely spaced, S_3 (109.92) and the wider spaced (S_2) for a longer period (111.83).

The interaction effects were significant with the shortest duration in N_4S_1 and N_3S_1 (106.00 each) followed by N_3S_3 (107.00) and the longest in N_2S_2 (115.67) followed by others.

4.10. Plant dry weight (g plant^{-1}) (Table 4.9)

The effect of nutrient levels and spacing were significant with the highest plant dry weight in N_1 (82.13) followed by N_2 (77.49) and N_4 (70.31) and the lowest in N_3 (65.62). The widest spaced plants (S_1) produced the highest dry weight (94.95) and the closely spaced (S_3), the lowest (50.75).

The interaction effects were significant with the highest dry weight in N_1S_1 (103.93) followed by N_2S_1 (100.18) and the lowest in N_3S_3 (40.94).

4.11. Plant nutrient uptake (Table 4.9)

4.11.1. Nitrogen (kg ha^{-1})

The effect of nutrient levels and spacing were significant with the highest uptake in N_4 (204.40) followed by N_1 (180.49) and N_2 (146.44) and the lowest in

Table 4.9. Effect of nutrient levels and spacing on crop duration, plant dry weight and nutrient uptake

Treatments	Crop duration (days)	Plant dry weight (g plant^{-1})	Uptake of Nitrogen (N in kg ha^{-1})	Uptake of Phosphorus (P_2O_5 in kg ha^{-1})	Uptake of Potassium (K_2O in kg ha^{-1})
Nutrient levels (N)					
N_1	111.44	82.13	180.49	32.48	216.83
N_2	112.22	77.49	146.44	26.36	197.25
N_3	107.44	65.62	118.85	21.39	155.27
N_4	109.33	70.31	204.40	36.64	142.33
S.E.	0.249	0.599	1.473	0.264	1.352
C.D (0.05)	0.730	1.757	4.320	0.775	3.965
Spacing (S)					
S_1	108.58	94.99	156.27	28.13	169.96
S_2	111.83	75.92	163.29	29.29	179.17
S_3	109.92	50.75	168.07	30.24	184.64
S.E.	0.216	0.519	1.275	0.229	1.171
C.D (0.05)	0.633	1.521	3.741	0.671	3.434
Nutrient levels (N) x Spacing (S)					
N_1S_1	112.67	103.93	175.30	31.55	209.97
N_1S_2	112.67	86.55	179.39	32.29	217.88
N_1S_3	109.00	55.92	186.79	33.62	222.63
N_2S_1	109.67	100.18	142.38	25.63	186.06
N_2S_2	115.67	81.12	145.51	26.19	202.49
N_2S_3	111.33	51.16	151.43	27.26	203.21
N_3S_1	106.00	86.55	110.23	19.84	148.74
N_3S_2	109.33	69.37	121.70	21.91	153.29
N_3S_3	107.00	40.94	124.62	22.43	163.79
N_4S_1	106.00	89.31	197.18	35.49	135.06
N_4S_2	109.67	66.65	206.58	36.79	143.02
N_4S_3	112.33	54.98	209.45	37.65	148.92
S.E.	0.431	1.037	2.550	0.458	2.341
C.D (0.05)	1.265	3.043	NS	NS	NS

N_3 (118.85). The highest uptake was in the closely spaced, S_3 (168.07) followed by the wider spaced (S_2) and the widest spaced (S_1), the lowest (156.27).

4.11.2. Phosphorus (kg ha^{-1})

The effect of nutrient levels and spacing were significant and the uptake of phosphorus showed a similar trend as that of nitrogen. The highest uptake was in N_4 (36.64) followed by N_1 (32.48) and N_2 (26.36) and the lowest in N_3 (21.39). The closely spaced plants (S_3) showed the highest uptake (30.24) followed by the wider spaced, S_2 (29.29) and the widest spaced (S_1), the lowest (28.13).

The interaction effects were not significant.

4.11.3. Potassium (kg ha^{-1})

The effect of nutrient levels and spacing were significant with the highest uptake in N_1 (216.83) followed by N_2 (197.25) and N_3 (155.27) and the lowest in N_4 (142.33). The closely spaced plants (S_3) showed the highest uptake (184.64) followed by the wider spaced, S_2 (179.17) and the widest spaced (S_1), the lowest (169.96).

The interaction effects were not significant.

4.12. Soil analysis after the experiment (Table 4.10)

4.12.1. Organic carbon (%)

The effect of nutrient levels was significant with the highest organic carbon content in N_1 (0.689) followed by N_2 (0.631) and N_3 (0.610) and the lowest in N_4 (0.592).

The effect of spacing was not significant.

The interaction effects were significant with the highest organic carbon content in N_1S_2 (0.693) followed by N_1S_3 (0.690) and N_1S_1 (0.684) and all were on par with each other and the lowest in N_4S_1 (0.583).

Table 4.10. Effect of nutrient levels and spacing on soil nutrient content after the experiment.

Treatments	Organic carbon (%)	Available Nitrogen (N in kg ha^{-1})	Available Phosphorus (P_2O_5 in kg ha^{-1})	Available Potassium (K_2O in kg ha^{-1})
Nutrient levels (N)				
N_1	0.689	251.83	121.96	91.32
N_2	0.631	237.77	107.25	72.56
N_3	0.610	218.61	93.81	75.00
N_4	0.592	202.95	86.95	76.57
S.E.	0.001	1.826	0.65	1.431
C.D (0.05)	0.003	5.355	1.906	4.196
Spacing (S)				
S_1	0.625	234.78	104.48	86.00
S_2	0.632	227.26	102.37	78.15
S_3	0.635	221.32	100.61	72.42
S.E.	0.001	1.581	0.563	1.24
C.D (0.05)	NS	NS	NS	3.634
Nutrient levels (N) x Spacing (S)				
N_1S_1	0.684	257.70	123.01	98.00
N_1S_2	0.693	252.33	122.16	89.96
N_1S_3	0.690	245.45	120.72	85.99
N_2S_1	0.625	240.60	109.37	82.74
N_2S_2	0.630	241.21	108.80	69.34
N_2S_3	0.640	231.51	103.57	65.60
N_3S_1	0.607	231.78	96.82	81.26
N_3S_2	0.612	213.30	93.03	77.52
N_3S_3	0.611	210.75	91.57	66.21
N_4S_1	0.583	209.04	88.74	82.00
N_4S_2	0.592	202.22	85.52	75.80
N_4S_3	0.601	197.59	86.58	71.90
S.E.	0.002	3.162	1.125	2.478
C.D (0.05)	0.006	NS	NS	NS

4.12.2. Available nitrogen (kg ha^{-1})

The effect of nutrient levels was significant with the highest available nitrogen content in N_1 (251.83) followed by N_2 (237.77) and N_3 (218.61) and the lowest in N_4 (202.95).

Plant spacing and interaction effects were not significant.

4.12.3. Available phosphorus (kg ha^{-1})

The effect of nutrient levels was significant and the phosphorus content in soil followed a similar trend as that of nitrogen with the highest available phosphorus in N_1 (121.96) followed by N_2 (107.25) and N_3 (93.81) and the lowest in N_4 (86.95).

Plant spacing and interaction effects were not significant.

4.12.4. Available potassium (kg ha^{-1})

The effect of nutrient levels and spacing were significant and the available potassium content was the highest in N_1 (91.32) and the lowest in N_2 (72.56) which was on par with N_4 (76.57) and N_3 (75.00). The widest spaced plants (S_1) left more potassium in the soil (86.00) followed by the wider spaced (S_2) and the closely spaced (S_3), the least (72.42).

The interaction effects were not significant.

4.13. Benefit-Cost ratio (B:C ratio) (Table 4.11)

4.13.1. B:C ratio at normal market price

The effect of nutrient levels and spacing were significant with the highest B:C ratio in N_4 (1.76) followed by N_1 (1.09) and N_2 (0.82) and the lowest in N_3 (0.61). The closely spaced (S_3) plants recorded the highest B:C ratio of 1.17

Table 4.11. Effects of nutrient levels and spacing on Benefit-Cost ratio at normal and premium prices

Treatments	B:C ratio at normal price	B:C ratio at premium price
Nutrient levels (N)		
N_1	1.09	1.31
N_2	0.82	0.98
N_3	0.61	0.73
N_4	1.76	1.76
S.E.	0.009	0.010
C.D (0.05)	0.027	0.031
Spacing (S)		
S_1	0.99	1.12
S_2	1.04	1.17
S_3	1.17	1.30
S.E.	0.008	0.009
C.D (0.05)	0.023	0.027
Nutrient levels (N) x Spacing (S)		
N_1S_1	1.06	1.27
N_1S_2	1.07	1.29
N_1S_3	1.13	1.36
N_2S_1	0.80	0.96
N_2S_2	0.81	0.98
N_2S_3	0.85	1.02
N_3S_1	0.56	0.68
N_3S_2	0.62	0.75
N_3S_3	0.64	0.77
N_4S_1	1.56	1.56
N_4S_2	1.67	1.67
N_4S_3	2.05	2.05
S.E.	0.016	0.018
C.D (0.05)	0.047	0.053

followed by the wider spaced, S_2 (1.04) and the widest spaced (S_1), the lowest (0.99).

The interaction effects were significant with the highest B:C ratio in N_4S_3 (2.05) followed by N_4S_2 (1.67), N_4S_1 (1.56) and N_1S_3 (1.13) and the lowest in N_3S_1 (0.56). The treatments N_3S_3 and N_3S_2 also recorded B:C ratios less than one.

4.13.2. B:C ratio at premium price

Assuming a 20% hike for the organic produce in the market (considered as the premium price), B:C ratio was determined at the premium price. The effect of nutrient levels and spacing were significant with the highest B:C ratio in N_4 (1.76) followed by N_1 (1.31) and N_2 (0.98) and the lowest in N_3 (0.73). The closely spaced (S_3) plants recorded the highest B:C ratio (1.30) followed by the wider spaced, S_2 (1.17) and the widest spaced (S_1), the lowest (1.12).

The interaction effects were significant with the highest B:C ratio in N_4S_3 (2.05) followed by N_4S_2 (1.67), N_4S_1(1.56) ,N_1S_3 (1.36) and the lowest in N_3S_1 (0.68). The treatments N_3S_3 and N_3S_2 were also recorded B:C ratios less than one.

4.14. Residual crop - Amaranthus

4.14.1. Growth characters (Table 4.12)

The major growth characters recorded include plant height, leaves plant^{-1} and leaf area index (LAI). All these observations were recorded at 40 DAS i.e., just before the flowering stage of the crop.

4.14.1.1. Plant height (cm)

The effect of nutrient levels was significant with the tallest plants in N_4 (48.82) followed by N_1 (35.93) and N_2 (33.50) and the shortest in N_3 (25.72).

Plant spacing and interaction effects were not significant.

Table 4.12. Effect of nutrient levels and spacing on growth characters of residual crop - Amaranthus

Treatments	Plant height (cm)	Number of leaves	Leaf Area Index (LAI)
Nutrient levels (N)			
N_1	35.93	51.91	1.780
N_2	33.50	44.02	1.656
N_3	25.72	36.71	1.543
N_4	48.82	54.12	2.194
S.E.	0.991	0.988	0.007
C.D (0.05)	2.905	2.898	0.020
Spacing (S)			
S_1	35.76	46.46	1.785
S_2	35.62	46.25	1.791
S_3	36.60	47.36	1.804
S.E.	0.858	0.855	0.004
C.D (0.05)	NS	NS	NS
Nutrient levels (N) x Spacing (S)			
N_1S_1	35.21	52.53	1.763
N_1S_2	36.75	52.16	1.778
N_1S_3	35.82	51.04	1.799
N_2S_1	32.73	42.01	1.623
N_2S_2	31.66	43.51	1.674
N_2S_3	36.10	46.53	1.671
N_3S_1	27.62	37.80	1.532
N_3S_2	24.58	35.37	1.543
N_3S_3	24.95	36.95	1.555
N_4S_1	47.48	53.48	2.222
N_4S_2	49.47	53.97	2.168
N_4S_3	49.51	54.92	2.193
S.E.	1.716	1.711	0.012
C.D (0.05)	NS	NS	0.035

4.14.1.2. Leaves plant^{-1}

The effect of nutrient levels was significant with the highest leaf production in N_4 (54.12) followed by N_1 (51.91), which were on par and the lowest in N_3 (36.71).

Plant spacing and interaction effects were not significant.

4.14.1.3. Leaf Area Index (LAI)

The effect of nutrient levels was significant with the highest LAI in N_4 (2.194) followed by N_1 (1.780) and the lowest in N_3 (1.543).

The interaction effects were significant with the highest LAI in N_4S_1 (2.222) followed by N_4S_3 (2.193) and N_4S_2 (2.168) and were on par with each other. The lowest LAI was in N_3S_1 (1.532) and was on par with N_3S_2 (1.543) and N_3S_3 (1.555).

4.15. Dry weight of plants (g plant^{-1}) (Table 4.13)

The effect of nutrient levels, plant spacing and interactions were not significant.

4.16. Uptake of nutrients (Table 4.13)

4.16.1. Nitrogen (kg ha^{-1})

The effect of nutrient levels was significant with the highest uptake in N_4 (157.62) followed by N_1 (138.71) and N_2 (112.90) and the lowest in N_3 (102.55).

Plant spacing and interaction effects were not significant.

4.16.2. Phosphorus (kg ha^{-1})

The effect of nutrient levels was significant with the highest uptake in N_1 (19.19) followed by N_2 (15.45) and N_4 (15.30) which were on par and the lowest in N_3 (13.34).

Table 4.13. Effect of nutrient levels and spacing on dry weight, nutrient uptake and yield of residual crop - Amaranthus

Treatments	Plant dry weight (g $plant^{-1}$)	Uptake of Nitrogen (N in kg ha^{-1})	Uptake of Phosphorus (P_2O_5 in kg ha^{-1})	Uptake of Potassium (K_2O in kg ha^{-1})	Yield (t ha^{-1})
Nutrient levels (N)					
N_1	24.16	138.71	19.19	60.99	21.68
N_2	20.72	112.90	15.45	55.12	14.07
N_3	18.58	102.55	13.34	51.42	12.83
N_4	26.61	157.62	15.30	66.77	25.16
S.E.	0.096	0.674	0.064	0.112	0.090
C.D (0.05)	NS	1.977	0.188	0.328	0.264
Spacing (S)					
S_1	22.14	127.86	15.71	57.72	18.20
S_2	22.56	128.98	15.85	58.38	18.52
S_3	22.85	126.99	15.90	59.64	18.59
S.E.	0.083	0.584	0.056	0.097	0.078
C.D (0.05)	NS	NS	NS	NS	NS
Nutrient levels (N) x Spacing (S)					
N_1S_1	23.67	139.96	18.99	60.10	21.41
N_1S_2	24.22	137.54	19.23	61.04	21.78
N_1S_3	24.58	138.63	19.35	61.84	21.85
N_2S_1	20.09	112.34	15.47	55.09	13.76
N_2S_2	20.95	114.20	15.38	55.05	14.09
N_2S_3	21.13	112.15	15.48	55.23	14.36
N_3S_1	18.54	100.82	13.24	50.52	12.90
N_3S_2	18.49	104.81	13.45	51.27	12.88
N_3S_3	18.72	102.03	13.32	52.46	12.72
N_4S_1	26.28	158.32	15.13	65.15	24.72
N_4S_2	26.59	159.38	15.32	66.14	25.31
N_4S_3	26.97	155.16	15.44	69.03	25.44
S.E.	0.165	1.167	0.111	0.194	0.156
C.D (0.05)	NS	NS	NS	0.568	NS

Plant spacing and interaction effects were not significant.

4.16.3. Potassium (kg ha^{-1})

The effect of nutrient levels was significant with the highest uptake in N_4 (66.77) followed by N_1 (60.99) and N_2 (55.12) and the lowest in N_3 (51.42).

The effect of plant spacing was not significant.

The interaction effects were significant with the highest uptake in N_4S_3 (69.03) followed by N_4S_2 (66.14) and N_4S_1 (65.15) which were on par and the lowest in N_3S_1 (50.52) and was on par with N_3S_2 (51.27) and N_3S_3 (52.46).

4.17. Marketable yield of amaranthus (t ha^{-1}) (Table 4.13)

The effect of nutrient levels was significant with the highest in N_4 (25.16) followed by N_1 (21.68) and N_2 (14.07) and the lowest in N_3 (12.83).

Plant spacing and interaction effects were not significant.

4.18. Benefit-cost ratio (B:C ratio) (Table 4.14)

The effect of nutrient levels was significant with the highest B:C ratio in N_4 (1.94) followed by N_1 (1.67) and N_2 (1.08) and the lowest in N_3 (0.99).

Plant spacing and interaction effects were not significant.

4.19. Combined B:C Ratio (Table 4.14)

4.19.1. At normal market price

The effect of nutrient levels and spacing were significant with the highest B:C ratio in N_4 (1.80) followed by N_1 (1.20) and N_2 (0.87) and the lowest in N_3 (0.68). The closely spaced plants (S_3) recorded the highest B:C ratio (1.22) followed by the wider spaced, S_2 (1.12) and the widest spaced (S_1), the lowest (1.08).

Table 4.14. Effect of nutrient levels and spacing on economics of residual crop amaranthus and tomato-amaranthus sequence

Treatments	B:C ratio of amaranthus	B:C ratio of tomato-amaranthus sequence at normal market price	B:C ratio of tomato-amaranthus sequence at premium price
Nutrient levels (N)			
N_1	1.67	1.20	1.38
N_2	1.08	0.87	1.00
N_3	0.99	0.68	0.78
N_4	1.94	1.80	1.79
S.E.	0.007	0.007	0.008
C.D (0.05)	0.020	0.022	0.025
Spacing (S)			
S_1	1.40	1.08	1.17
S_2	1.42	1.12	1.22
S_3	1.43	1.22	1.32
S.E.	0.004	0.006	0.007
C.D (0.05)	NS	0.019	0.021
Nutrient levels (N) x Spacing (S)			
N_1S_1	1.65	1.18	1.35
N_1S_2	1.68	1.19	1.36
N_1S_3	1.68	1.24	1.42
N_2S_1	1.06	0.85	0.97
N_2S_2	1.08	0.87	0.99
N_2S_3	1.10	0.90	1.03
N_3S_1	0.99	0.65	0.74
N_3S_2	0.99	0.70	0.80
N_3S_3	0.98	0.71	0.81
N_4S_1	1.90	1.63	1.63
N_4S_2	1.95	1.72	1.72
N_4S_3	1.96	2.03	2.03
S.E.	0.011	0.013	0.015
C.D (0.05)	NS	0.037	0.043

The interaction effects were significant with the highest B:C ratio in N_4S_3 (2.03) followed by N_4S_2 (1.72) and N_4S_1 (1.63) and the lowest in N_3S_1 (0.65). The treatments N_3S_3 and N_3S_2 were also recorded B:C ratios less than one.

4.19.2. At premium price

Assuming a 20 % hike for the organic produce in the market (taken as the premium price), B:C ratio was determined at the premium price for tomato plus the market price of amaranthus. The effect of nutrient levels and spacing were significant with the highest B:C ratio in N_4 (1.79) followed by N_1 (1.38) and N_2 (1.00) and the lowest in N_3 (0.78). The closely spaced plants (S_3) recorded the highest B:C ratio (1.32) followed by the wider spaced, S_2 (1.22) and the widest spaced, S_1 (1.17).

The interaction effects were significant with the highest B:C ratio in N_4S_3 (2.03) followed by N_4S_2 (1.72) and N_4S_1 (1.63) and the lowest in N_3S_1 (0.74). The treatments N_3S_3 and N_3S_2 were also recorded B:C ratios less than one.

DISCUSSION

5. DISCUSSION

The results of the experiment to develop production protocol of organic tomato involving organic nutrition, plant population and plant protection are discussed below. Economics of organic nutrition of tomato and the residual effect of organic nutrition on the succeeding amaranthus crop is also discussed.

5.1. The tomato crop

All treatments including the various nutrient levels and plant spacing had significant effect upon majority of the growth, yield and fruit quality parameters of tomato.

5.1.1. Growth characters

Major plant growth characters analyzed did include plant height, leaves plant^{-1}, branches plant^{-1} including secondary branches and leaf area index.

5.1.1.1. Plant height

Plants were observed to be taller in response to increased addition of nutrients particularly with integrated supply of nutrients rather than organic alone and increased spacing between the plants throughout the active growth phases. POP recommendation which is an integrated source of nutrients recorded the highest plant height followed by full organic nitrogen substitution throughout the major growth phases. In POP, the nutrients are in readily available form when compared to other sources. Influence of nitrogen in increasing the vegetative growth of the plant is a universally accepted fact. This increased growth characters may be due to the increased availability of nitrogen from chemical fertilizer. Increased nitrogen level increases the growth characters as reported by Joseph (1998). The plants were the shortest in 50% organic nitrogen substitution. These results on nutrient addition coincided with the findings of Reddy et al. (2002) who found that the plant height remained on par with recommended NPK rate and with 50% substitution by vermicompost. Similar results were obtained by Krishna and Krishnappa (2002); Raut et al. (2003); Patil et al. (2004); Rodge and

Yadlod (2009). Ge Tida et al. (2008) also made a similar finding that there was significant difference in plant height on 24 and 32 days after sowing with inorganic nitrogen in the form of NO_3^- being superior treatment followed by organic nitrogen.

Among the organic treatments the presence of vermicompost in small proportions improved plant growth as suggested by Atiyeh et al. (1999) and Azarmi et al. (2008). Arancon et al. (2003) suggested the production of hormones or humates in vermicompost acting as plant-growth regulators independent of nutrient supply. Not only purely physical and chemical properties of vermicompost are stimulating plant growth but there is also the possibility that indirect effects via the inhibition of plant pathogen infection (Szczech, 1999 and Zaller, 2006), effects on the rhizosphere microflora (Brito Alvarez et al., 1995), nitrate uptake kinetics (Dell'Agnola and Nardi, 1987 and Muscolo et al., 1999), effects on beneficial microorganisms (Atiyeh et al., 2000), plant growth regulators (Tomati et al., 1988) or mycorrhizal colonisation of roots (Cavender et al., 2003) might override pure nutrient effects.

The tallest plants were observed in the widest spacing of 60 cm x 60 cm and the shortest plants in close spacing of 60 cm x 30 cm. However the results were contradictory to the findings by Papadopoulos and Ormrod (1991) who reported that plant height and internode length increased significantly with successive decreases in plant spacing. However enhanced growth of plants under lower plant densities might have made the plants to become taller as reported by Heuvelink (1995a).

5.1.1.2. Leaves plant^{-1}

The number of leaves increased with increased supply of nutrients and the integrated application of nutrients based on the POP recommended control became the superior treatment followed by full organic nitrogen substitution. The leaf number was the lowest in 50% organic nitrogen substitution. These results coincide with the findings of Patil et al. (2004) and Rodge and Yadlod (2009)

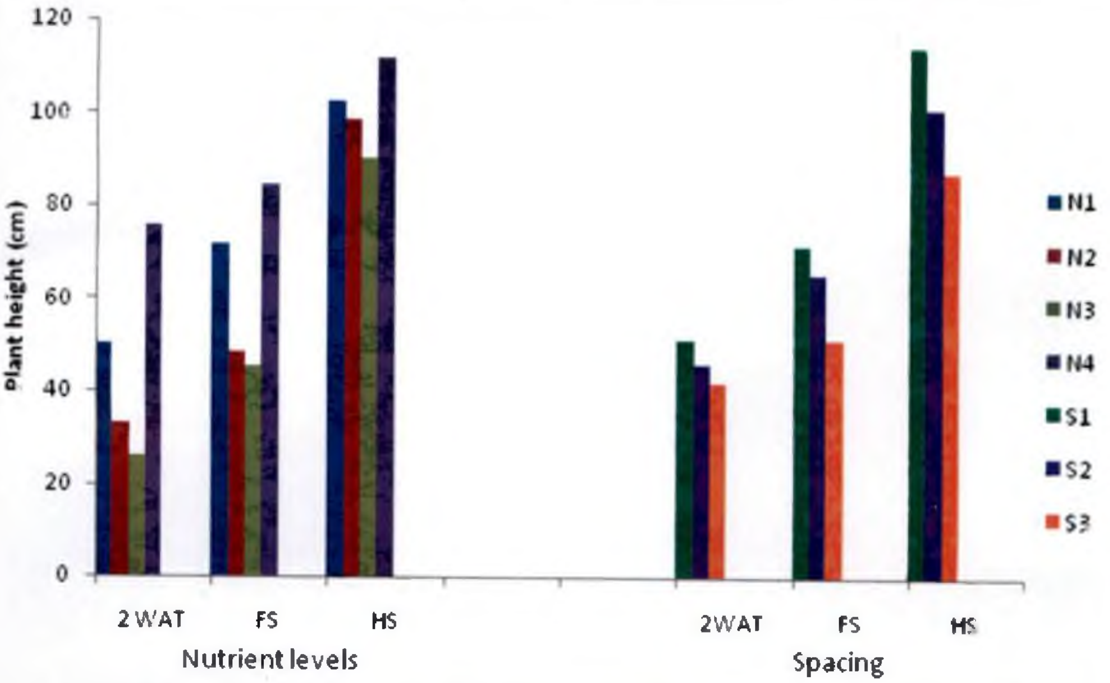

Fig 3. Effect of nutrient levels and spacing on plant height at different growth stages

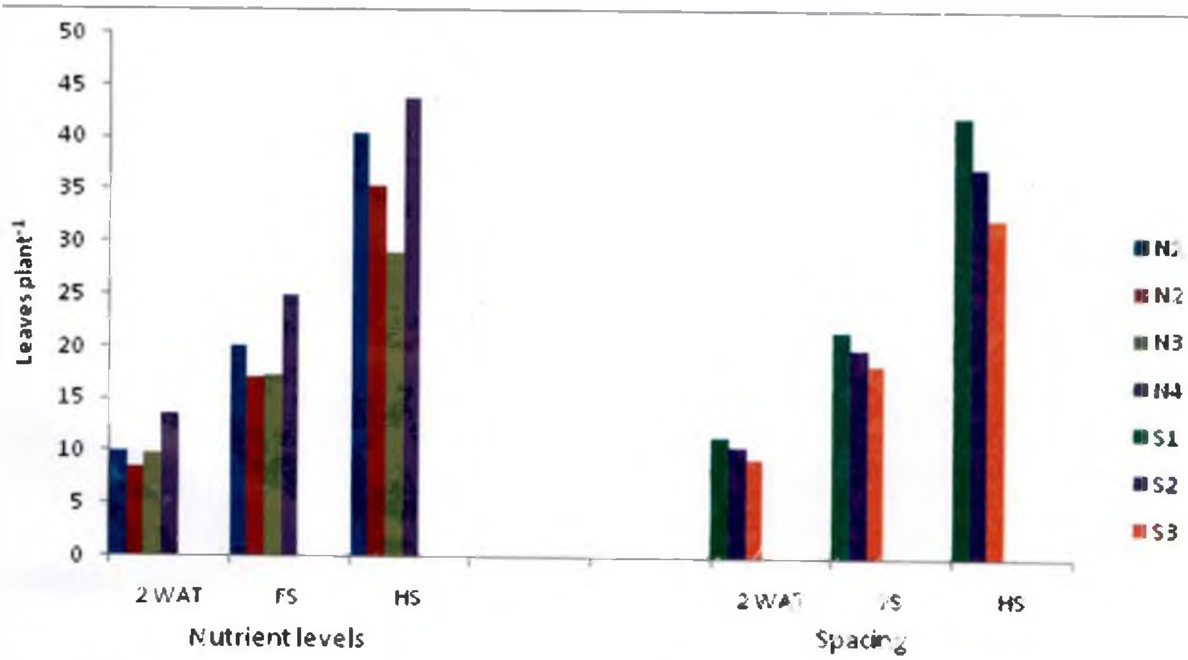

Fig 4. Effect of nutrient levels and spacing on number of leaves at different growth stages

WAT – weeks after transplanting **FS – Flowering stage** **HS – Harvesting stage**

who reported that integrated application of recommended fertilizers and FYM gave higher leaf numbers.

The beneficial effects of organic amendments in increasing the growth parameters was reported by Pushpa (1996) in tomato. Among the organic treatments, the presence of vermicompost in small proportions improved plant growth as suggested by Atiyeh et al. (1999) and Azarmi et al. (2008). The widely spaced plants produced more leaves than closely spaced ones. Ferry and Janick (1970) reported lowering of node number plant^{-1} with sharp increase in plant population. The finding is in proximity with the report of Zahara and Timm (1973) who found that the number of leaves decreased as plant population density increased which would have helped when plants are closely spaced.

5.1.1.3. Branches plant^{-1}

POP recommended integrated nutrient application recorded the highest branching and full organic nitrogen substitution did not increase the number of branches except at 1 month after planting. But the other two organic substitutions increased the branching of the plant at the initial and the harvest stages respectively. This is in accordance with the finding of Subler et al. (1998) and Atiyeh et al. (2000) that higher proportions of vermicomposts in nutrient mixture were not always improving plant growth. Raut et al. (2003) reported that the number of branches recorded in tomato plants increased when NPK plus farmyard manure were applied together.

The widest spaced plants produced more branches than closely spaced ones. Branching of the plant was the lowest in 60 cm x 30 cm spacing. This observation can be correlated with the findings of Heuvelink (1995a) who reported that plant growth was strongly influenced by plant density, the highest plant growth rate occurring at the lowest plant density.

Kumaran et al. (1998) showed that the number of branches plant^{-1} was the best with organic plus inorganic fertilizers, *Azospirillium* and Phosphobacteria and perhaps the rock phosphate enriched vermicompost with *Azospirillum* and Phosphobacteria would have increased the branch number in organic plots.

5.1.1.4. Leaf Area Index

POP recommended treatment with integrated supply of FYM and chemical fertilizers recorded the highest LAI especially at the initial and the flowering stages of plant. Among the organic treatments, full organic nitrogen substitution was the best followed by 75% and 50% substitution. The results are assisted with the findings of Patil et al. (2004); Rodge and Yadlod (2009) that integrated application of fertilizers and organic manures (especially FYM) increased the number of leaves within tomato plants and the increase in leaf number plant^{-1} enhanced an increase in the leaf area index too.

Rather than nutrient schedule, the leaf area index is much more depended upon the plant density or spacing. In the initial growth stages and at flowering, spacing effect was significant with the closely spaced (60 cm x 30 cm) plants recording the highest leaf area index. But the spacing effect became insignificant at the later growth stage (harvest stage). Tanaka and Komochi (1982) reported that in tomato, the leaf size and leaf weight decreased with increase in planting density. This could be the reason for the insignificant influence of plant spacing upon the LAI at the later growth stages of the crop. At the later stages, though the leaf number per unit area might have been higher for closely spaced plants, but the leaf size and area would have been lower to make LAI insignificant. The result is in accordance with the reports of Nederhoff (1984) who observed higher LAI at higher tomato plant densities (closer spacing).

5.1.2. Flower and flowering characters

5.1.2.1. Days to first flowering

Delayed flowering was observed in 75% organic nitrogen substitution whereas normal flowering in full organic nitrogen substitution and control (POP recommendation). It was found out that addition of 50% vermicompost to the

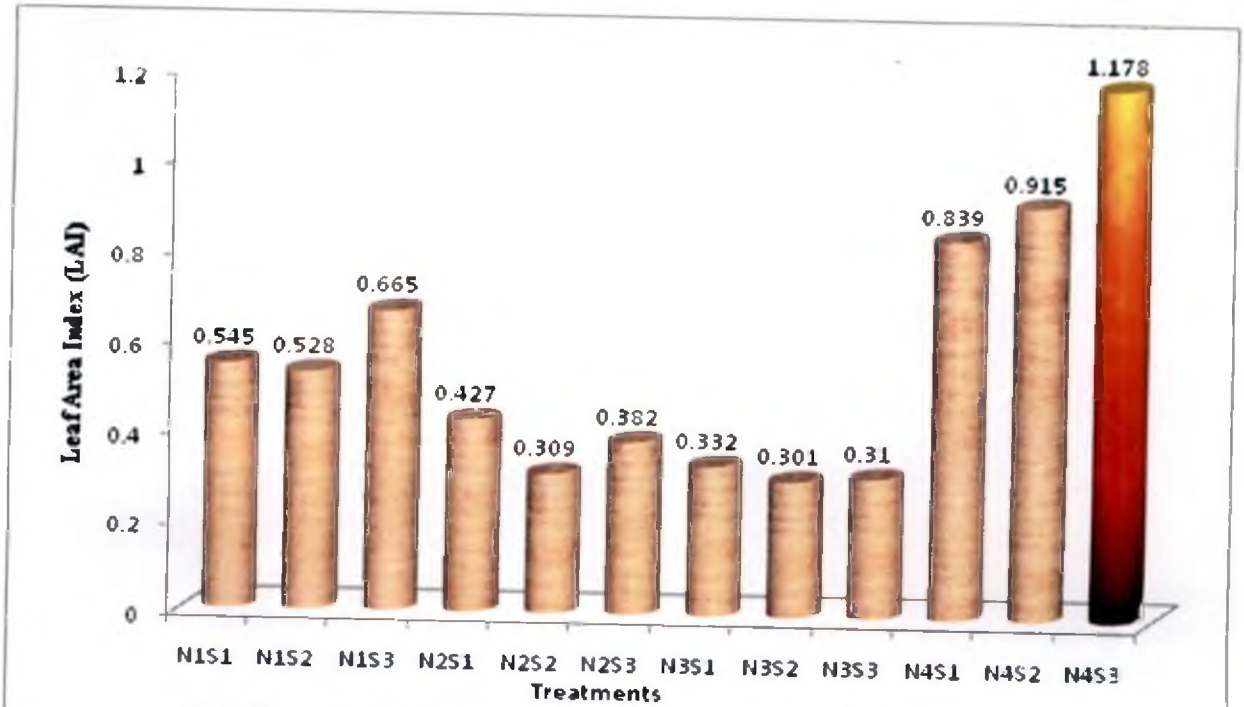

Fig 5. Treatment effect on leaf area index at flowering stage

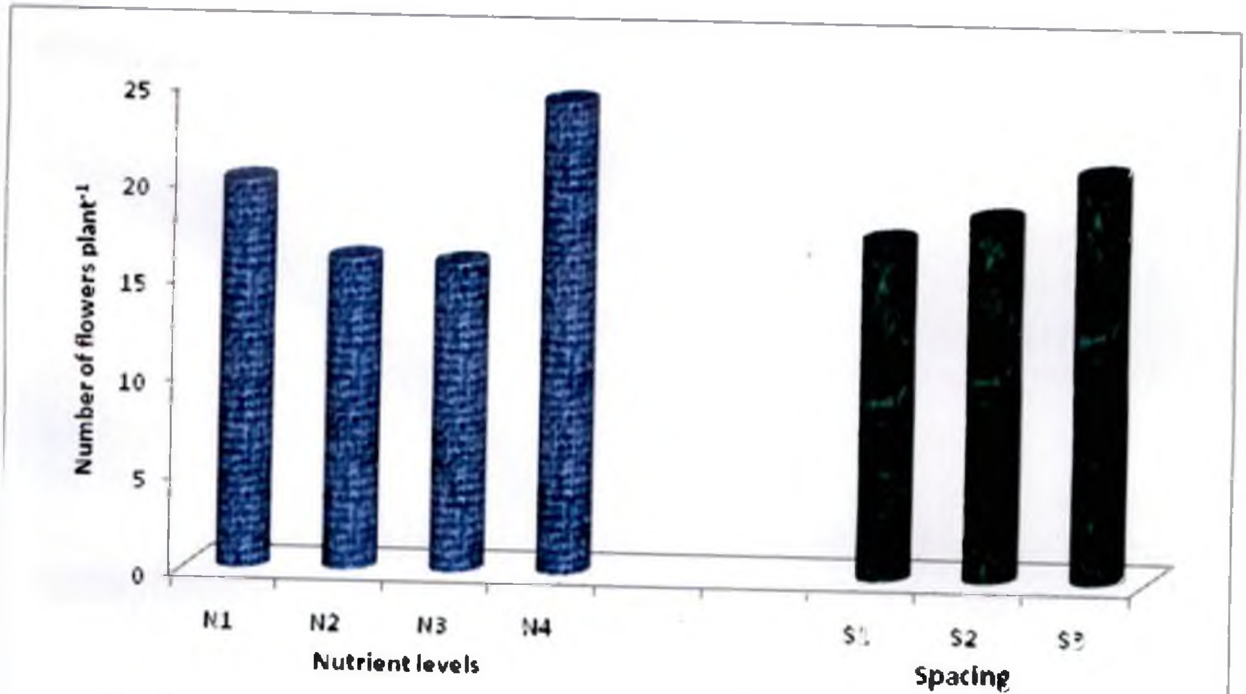

Fig 6. Effect of nutrient levels and spacing on number of flowers $plant^{-1}$

growth medium made the flowering in tomato earlier by 10 days (Rodriguez et al., 2007). Early flowering found in 50% organic nitrogen substitution and this could be due to the reduced supply of nutrients which put the plants to a little stressed condition thereby forcing the plants to flower early. This finding is similar to the report of Kolar and Senkova (2008) that the reduction of mineral nutrient availability to plants accelerated flowering.

Spacing was significant in tomato with respect to earliness in truss appearance. Delayed flowering observed in the widest and wider spaced plants compared to closer planting. This observation reverberates the report of Fawusi (1977) who found out in a factorial experiment that the time to 50% flowering in tomato was delayed by wide within row spacing.

5.1.2.2. Flowering intensity percentage

The control treatment (POP recommendation) with integrated supply of FYM and chemical fertilizers recorded maximum flowering intensity of 95% at 65 DAS followed by full organic nitrogen substitution. Other organic nitrogen substitutions recorded the lowest intensity (66% to 67%). The low flowering intensity in other organic treatments might be because of low phosphorus applications that reduced the final number of flowers as reported by Besford (1979).This emphasizes on the assimilation of adequate nutrient supply provided by full organic nitrogen substitution as well as POP recommendation and hence resulted in uniform flowering. This observation also showed that the actual flowering performance of the crop is revealed only towards the end of its flowering period after complete assimilation of the absorbed nutrients. At 55 DAS, the closely spaced (60 cm x 30 cm) plants recorded higher flowering intensity than the widely spaced ones. But, this deviation vanished in a gap of 10 days and further, the spacing effect became insignificant.

5.1.2.3. Flowers plant^{-1}

At 45 DAS, majority of the plants did not bloom. The reduced availability of nutrients might have helped the plants to flower early in the case of 50% and 75% of organic nitrogen substitution while in the control (POP recommended) plots, none of the plants flowered at 45 DAS. These findings are in accordance with those of Kolar and Senkova (2008) who suggested that the reduction of mineral nutrient availability to plants accelerated flowering. The control treatment (POP recommendation) corresponding to integrated application of farmyard manure and NPK fertilizers supplying full dose of the required nutrients to the crop evolved as the superior treatment throughout the flowering period from 55 DAS onwards with maximum number of flowers $plant^{-1}$. It was followed by full organic nitrogen substitution. The 75% organic nitrogen substitution recorded lower number of flowers at 55 DAS, but during the later stages, 50% organic nitrogen substitution recorded the least number of flowers. Krishna and Krishnappa (2002) reported that NPK application plus farmyard manure recorded the highest number of flower clusters $plant^{-1}$ in tomato crop. The low organic treatments might not have supplied the sufficient quantities of phosphorus to plants which would have resulted in reduced flower clusters $plant^{-1}$.

Phosphorus deficiency leads to reduced number of flower buds and delays the anthesis as reported by Menary and Staden (1976). Sufficient supply of rockphosphate enriched vermicompost by the high organic treatment could have increased the number of blossoms within the plant. One reason behind this may be due to the presence of growth regulators in vermicompost as reported by Krishnamoorthy and Vajranabhaiah (1986); Grappelli et al. (1987); Tomati et al. (1990) and Arancon et al. (2003).

Closely spaced plants (60 cm x 30 cm) had higher number of blossoms than others and this trend followed until the full bloom stage at 75 DAS. However, these results were contradicting the report of Ferry and Janick (1970) working with tomatoes, who found the number of clusters and the number of flowers $plant^{-1}$ decreased sharply as plant population increased. Similar incremental increases in total flowers $plant^{-1}$ and per cent fruit set at wider spacing have also been reported for greenhouse tomatoes (Rodriguez and Lambeth, 1975).

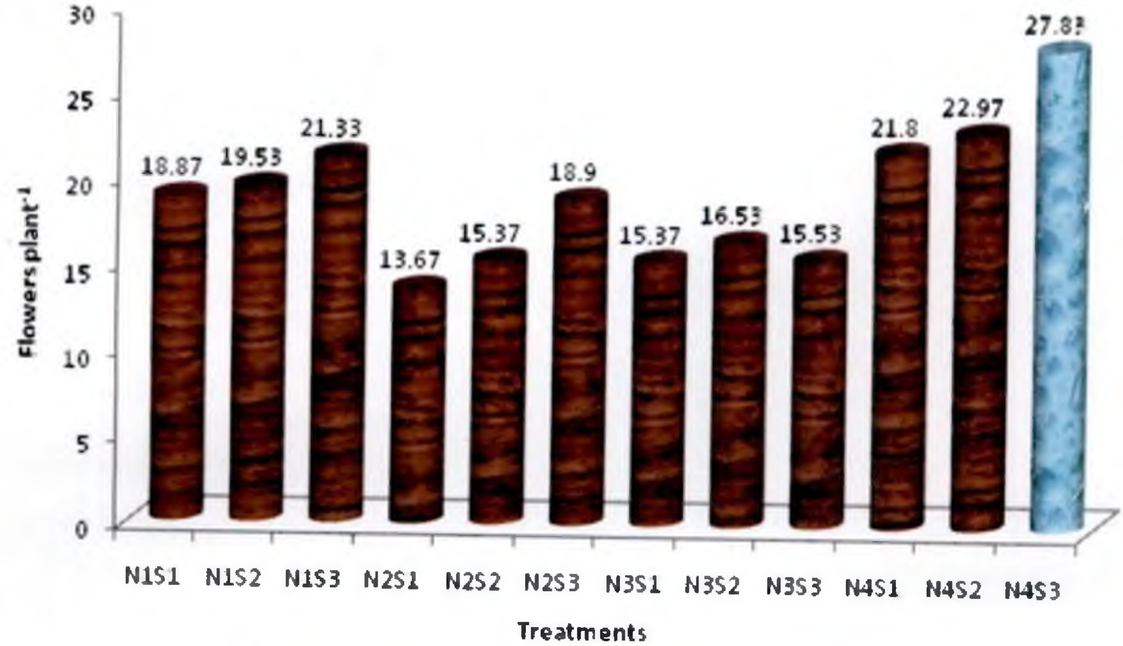

Fig 7. Treatment effect on number of flowers plant-1

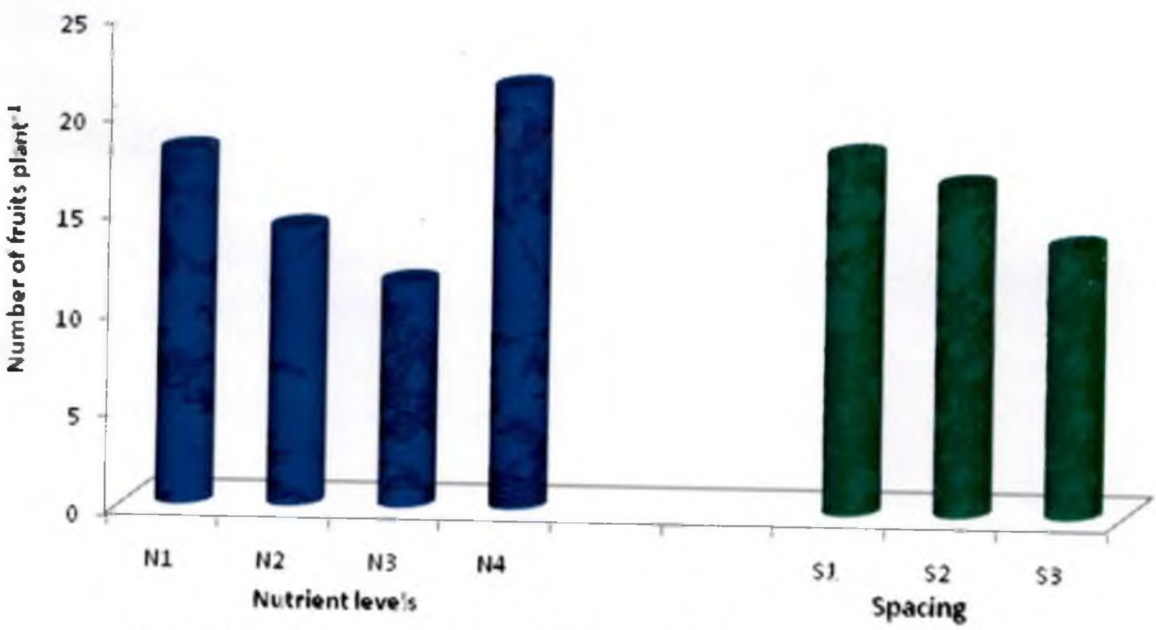

Fig 8. Effect of nutrient levels and spacing on the number of fruits plant-1

Perhaps, the higher plant density might have increased the number of leaves preceding the first inflorescence resulting in early flowering as suggested by Dieleman and Heuvelink (1992). But afterwards, flower abortion occurred in closely spaced plants that resulted in decreased fruit number during the later stages.

5.1.3. Fruit and fruiting characters

5.1.3.1. Fruiting intensity

Fruiting was observed from 60 DAS onwards and at 90 DAS, the entire plants bore fruits at their axils. According to Penalosa et al. (1988), the peak fruit development period lies between 60 and 90 DAT when about 50% of the total nutrient uptake takes place. Fruiting intensity increased from 60 DAS to 90 DAS on the whole. Fruiting was greatly affected by flower drops that occurred in the later growth stages of the crop. Fruiting intensity should be depended upon the intensity of flowering. However, the flower drops occurred has reduced the fruiting intensity. At 60 DAS, majority of the plants did not put fruits.

Full organic nitrogen substitution recorded high fruiting intensities throughout the fruiting period. The least fruiting intensity was recorded by the treatment that supplied 75% organic nitrogen. The presence of azospirillum and phosphate solubilizing bacteria enriched vermicompost might have enhanced fruiting in the plots subjected to the high organic treatment. Similar results were observed by Raut et al. (2003).

The fruiting intensity percentage was the highest with higher planting density when the plants were spaced close at 60 cm x 30 cm compared to wider spacings. However this effect became insignificant from 75 DAS onwards. This observation at the initial fruiting phase of the plant can be correlated with the flowering response discussed at an earlier session.

5.1.3.2. Fruits bunch^{-1}

The number of fruits bunch^{-1} depends on the number of flowers bunch^{-1} that have been properly developed and fertilized. However, enhanced flower abortion due to the hot climatic conditions reduced the fruit set. During periods of high temperature and low humidity the flower style elongates prior to dehiscence and can result in the flower failing to pollinate resulting in reduced fruit sets (Wittwer and Honma, 1979).

The POP recommendation with integrated supply of farmyard manure and NPK evolved as the superior treatment producing the highest number of fruits truss^{-1} followed by full organic nitrogen substitution which contained enriched vermicompost and farmyard manure in equal proportions. The number of fruits bunch^{-1} was the lowest in 50% organic nitrogen substitution. NPK application plus farmyard manure recorded higher fruits cluster^{-1} in tomato crop as reported by Krishna and Krishnappa, 2002. The application of recommended rates of N, P and K (100, 75 and 55 kg ha^{-1}respectively) with farmyard manure and vermicompost (250 and 12.5 quintal ha^{-1} respectively) was superior in terms of number of fruits cluster^{-1} in tomato cv. Naveen (Shukla et al., 2006).

The highest number of fruits truss^{-1} was recorded in the widest spaced plants and the lowest in closely spaced ones. Dense planting will lead to reduced light in the canopy. Cockshull et al. (1992) reported a reduction in number of fruits truss^{-1} at reduced light level. Low light intensities, short photoperiods and high night temperatures are important limiting factors to fruit set according to Wittwer and Honma (1979). However, Heuvelink (1995a) reported that the number of tomato fruits truss^{-1} was not affected by plant density.

5.1.3.3. Percentage fruit setting from flowers

High temperature prevailed during the crop reproductive stage had caused increased flower abortions as discussed earlier. This resulted in reduced fruit setting percentage from flowers. However full organic substitution could reduce blossom drops to a large extent as evident from the results. Phosphorus is an important nutrient for flower development, fruit set and to hasten fruit maturity. Sufficient supply of rockphosphate enriched vermicompost by the superior organic treatment could have raised the fruit set and number of blossoms within the plant. This might be due to the enhanced phosphorus uptake by the plants from enriched vermicompost as reported by Kumari and Usha kumari (2002).

5.1.3.4. Days to maturity of fruits

Soils into which farmyard manure has been incorporated contain enough soluble phosphoric acid as reported by Pal et al. (2001). The POP recommendation with integrated supply of farmyard manure and NPK took more time for fruit maturity compared to organic treatments. The 50% organic substitution took less time and the reason for earliness in ripening under organic treatments might be due to increased phosphorus availability to the crop resulting in enhanced beta carotene content of fruits. This is due to the presence of rockphosphate enriched vermicompost and abundant farmyard manure in the organic treatments. Enriched vermicompost enhanced phosphorus uptake by plants as reported by Kumari and Ushakumari (2002). It was found that with increased content of phosphorus in soil, the beta carotene content in fruit is increased which could be the cause of shortened fruit maturing process (Zdravkovic et al., 2007). Sreedevi et al. (2005) reported that vermicompost application to tomato crop resulted in significantly higher total carotenes and significant lower total carotenes when cultivated with chemical fertilizers. Early picking in tomato could be obtained with the application of vermicompost and phosphorus according to Shukla et al., 2006. Rinaldi et al. (2007) reported that the N availability during crop cycle influenced the date and simultaneous maturity of tomato fruits during the ripening process.

The widely spaced plants took more time for maturity compared to closely spaced ones. However, this observation is contradicting the observation of Tanaka and Komochi (1982) who studied the relationship between plant density and topping on the growth and yield of tomato in greenhouse and reported that with increasing plant density fruit ripening was delayed up to seven days. Perhaps the increased fruit load on widely spaced plants might have delayed the assimilate supply to the developing fruits.

5.1.3.5. Fruit yield plant $^{-1}$ (g plant^{-1})

Fruit yield plant^{-1} was generally low compared with the yield potential of the variety, 'Vellayani Vijai' being 1.34 kg plant^{-1}. This was because of increased flower abortions resulting from the hot conditions prevailed during the reproductive stage of the crop as discussed in an earlier session.

The highest fruit yield plant^{-1} was in POP recommendation with integrated application of farmyard manure and NPK fertilizers followed by full organic substitution. The lowest fruit yield was in 50% organic substitution. According to Krishna and Krishnappa (2002), NPK application plus farmyard manure recorded higher fruits plant^{-1} in tomato crop. Raut et al. (2003) reported higher fruit yields in tomato with integrated supply of NPK plus farmyard manure (FYM). He also reported that the higher number of fruits plant^{-1} was recorded with *azospirillum* plus phosphate solubilizing bacteria and fortunately, the vermicompost applied in case of organic amendments is enriched with *azospirillum* plus phosphate solubilizing bacteria. Moreover farmyard manure applied for organic treatments was subjected to trichoderma mass multiplication as common treatment. *Pseudomonas putida* and *Trichoderma atroviride* were shown to improve green house tomato fruit yields in organic medium (Valerie et al., 2007). These can be the reason for higher yields in case of superior organic treatments. Rodge and Yadlod (2009) found that in tomato, the yield plant^{-1} was significantly more in case of integrated application of 50% recommended fertilizer dose plus 50% farmyard manure.

Kumaran et al. (1998) studied the effect of inorganic and organic fertilizers on growth, yield and quality of tomato and the results showed that the number of fruits $plant^{-1}$ were the best with organic plus inorganic fertilizers, *azospirillium* and phosphobacteria.

The highest yield $crop^{-1}$ was obtained with the widest spacing of 60 cm x 60 cm. Close spacing has been shown to have a detrimental effect on fruit set apparently because of an inadequate supply of photosynthates due to shading (Zahara and Timm, 1973). Low light intensities, short photoperiods and high night temperatures are important limiting factors to fruit set (Wittwer and Honma 1979). Papadopoulos and Ormrod (1990) reported that the total and marketable yield $plant^{-1}$ declined linearly with successive increases in plant density. At closer spacing of tomato, the crop should be adequately fertilized to get higher yields as reported by Mehta et al. (2000).

The source-sink relations in response to planting density have already been discussed before. In an experiment on tomato conducted in a shade house established with 50% shade net, seedlings of tomato var. Himsona (indeterminate) were planted at three spacing treatments viz., 60 cm x 30 cm, 60 cm x 45 cm and 60 cm x 60 cm, it was observed that the mean yield $plant^{-1}$ for two seasons was maximum (3.67 kg $plant^{-1}$) in 60 cm x 60 cm spacing (Mantur and Sateesh, 2008).

5.1.3.6. Average fruit weight (g)

The POP recommendation corresponding to integrated supply of farmyard manure and NPK fertilizers recorded the heaviest fruits compared to the organic treatments. NPK application plus farmyard manure recorded higher fruit weight $plant^{-1}$ of tomato crop as reported by Krishna and Krishnappa (2002).

The application of recommended rates of N, P and K (100, 75 and 55 kg ha^{-1} respectively) with farmyard manure and vermicompost (250 and 12.5 quintal ha^{-1} respectively) was superior in terms of average fruit weight in tomato cv. Naveen (Shukla et al., 2006). Higher fruit weight in case of superior organic treatment could be due to the presence of *azospirillium* and phosphobacteria enriched vermicompost. Rodge and Yadlod (2009) also found out that heaviest

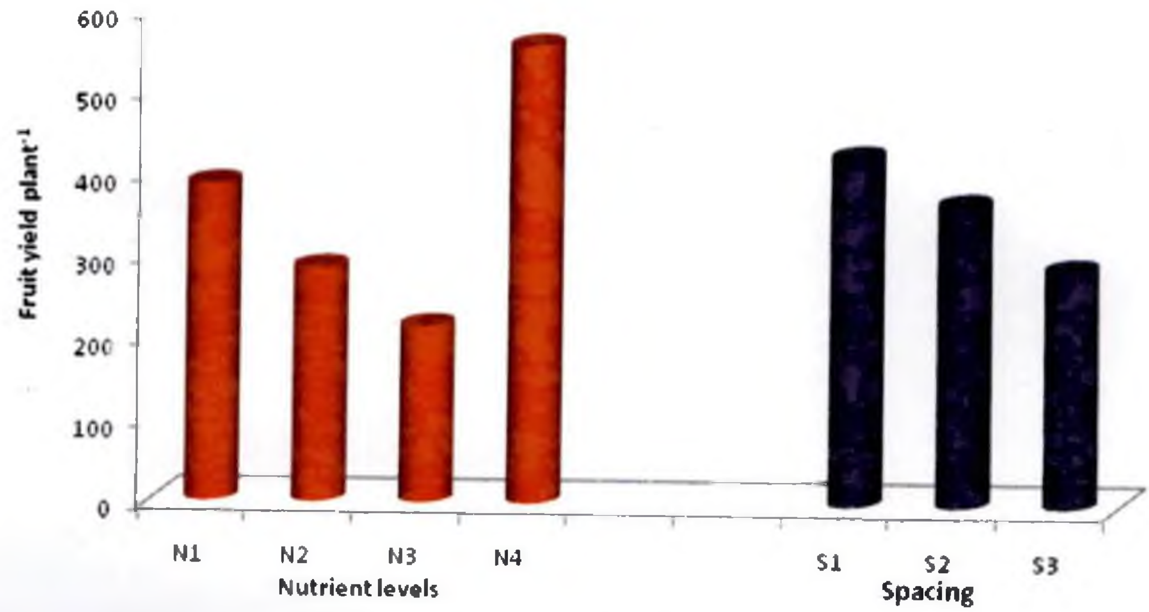

Fig 9. Effect of nutrient levels and spacing on fruit yield plant^{-1}

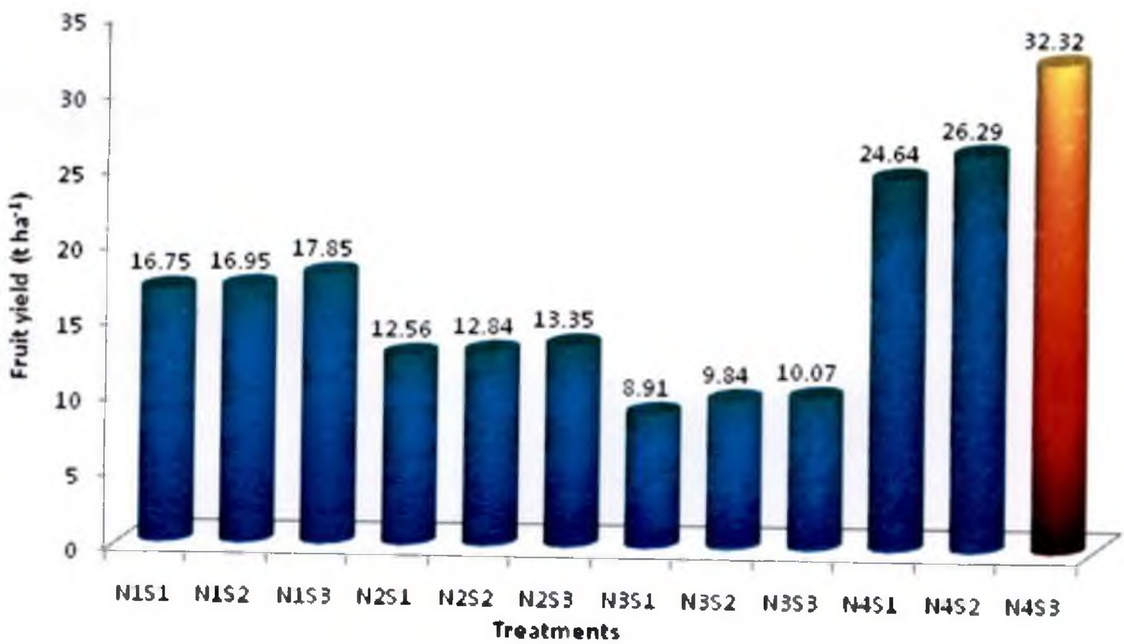

Fig 10. Treatment effect on fruit yield hectare^{-1}

tomato fruits were obtained in case of integrated application of 50% recommended fertilizer dose plus 50% farmyard manure.

Detrimental effect on fruit set apparently because of an inadequate supply of photosynthates due to shading is reported by Zahara and Timm (1973). The wider spacing of plants helped in setting heavier fruits and lighter fruits by close spacing. Saglam et al. (1995) reported that wider spacing for tomato gave heavier fruits plant^{-1} than closer spacing. Close spacing or high density planting led to increased shading and hence there occurred light reduction in the canopy.

5.1.3.7. Average fruit size (fruit girth in cm)

The POP recommendation with integrated supply of farmyard manure and NPK fertilizers produced large fruits followed by full organic substitution. The 50% organic nitrogen substitution put forth small sized fruits. The increased supply of nutrients to soil also increased the fruit size. Fruit and fruiting parts in tomato like group of vegetables contain 45 to 60% of total absorbed N, 50 to 60% of total absorbed P and 55 to 70% of total K absorbed by the plants according to Hegde (1997). Yoldas et al. (2009) reported that organic and inorganic fertilizers together significantly increased the fruit diameter and length in tomato. A study demonstrated that premature fruit drop can result in an increase in the size of neighbouring fruits.

The widely spaced plants produced fruits with maximum girth compared to the densely populated ones. Increased plant density can affect shading and low light conditions in the canopy leading to reduction in photosynthesis. The number of fruits competing for the assimilate is related to the number of plants squaremetre^{-1} (Ehret and Ho, 1986; Ho et al., 1987). Linear decline in fruit size with increasing plant density was observed by Papadopoulos and Ormrod (1990). Papadopoulos (1985) attributed this decline to reduction in the proportion of biomass allocated to the fruits. The production of smaller fruit under shade has been noted by Bailey and Hunter (1988). Cockshull et al. (1992) reported that shade increased the proportion of fruit in the small size grade. He concluded that smaller fruits were produced because the supply of assimilate was reduced proportionately more than the reduction in fruit number. Papadopoulos and Pararajasingham (1997) in an experiment to study the influence of plant spacing on light interception and use in greenhouse tomato reported that narrow spacings appeared to have detrimental effects on tomato fruit size.

5.1.3.8. Shelf life of fruits

The shelf life was the highest in 75% organic substitution and the lowest in POP recommendation (control). The organic treatments had farmyard manure and rockphosphate enriched vermicompost with *azospirillum* and phosphobacter in 1:1 proportion. Sreedevi et al. (2005) reported that among the organically and chemically cultivated tomato crops, vermicompost applied tomato crop had longer shelf life when stored at room temperature in kharif season. When the fruits were kept in 30 micron plastic cover, full organic substitution gave maximum shelf life and minimum with 50% substitution. Neem cake was used to mass multiply trichoderma with farmyard manure in the organic treatment. Enriched vermicompost took half the proportion of organic treatment. Sable et al. (2007) reported that the presence of neem cake and vermicompost enhanced for nitrogen supply to the tomato plants recorded higher shelf life for the fruits. Prabhakaran (2008) reported that application of 150 kg nitrogen hectare^{-1} in the form of urea decreased the shelf life of tomato fruits and fortunately the nitrogen source for the chemical fertilizer treatment in this experiment was urea and was responsible for the lowest shelf life in POP recommendation. Raut et al. (2003) also reported that farmyard manure plus *azospirillum* enhanced the shelf life of tomato fruits.

When the perishability of tomato fruits was evaluated in paper cover, full organic substitution and POP recommendation were found equally good. These results were in proximity with the reports of Patil et al. (2004) who substantiated that the storage life of fruits was the highest for 50% recommended fertilizer dose (RFD) plus 50% farmyard manure, 50% RFD plus 50 % vermicompost and 100% organic fertilizers [which included 25% farmyard manure (25 t ha^{-1}) and 25%

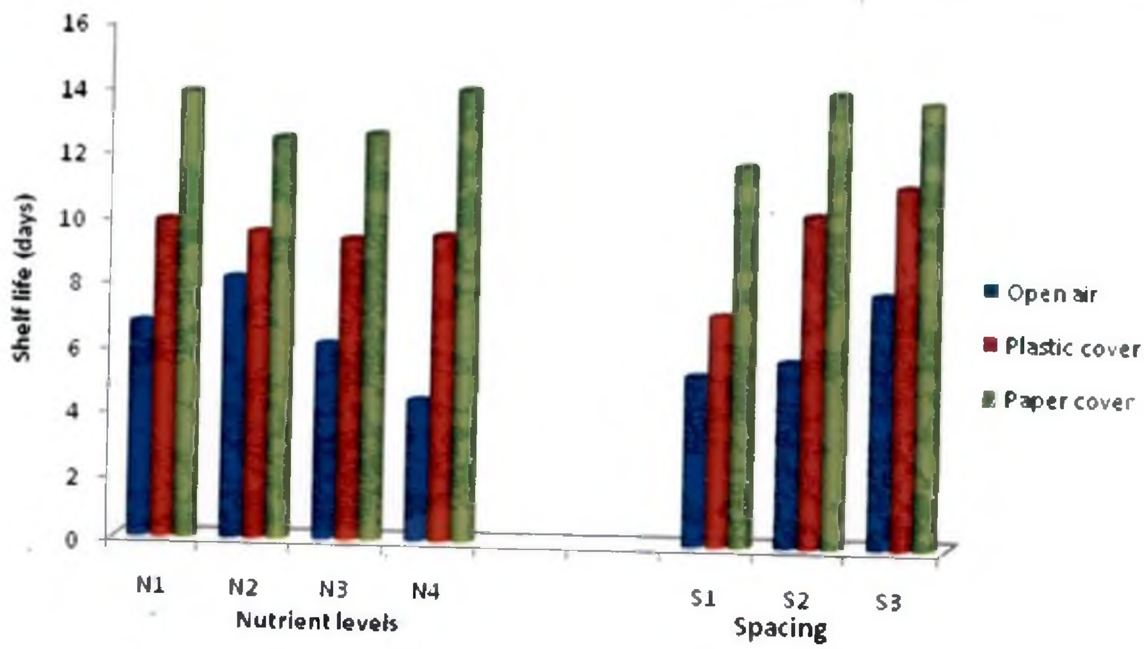

Fig 11. Effect of nutrient levels and spacing on shelf life of fruits

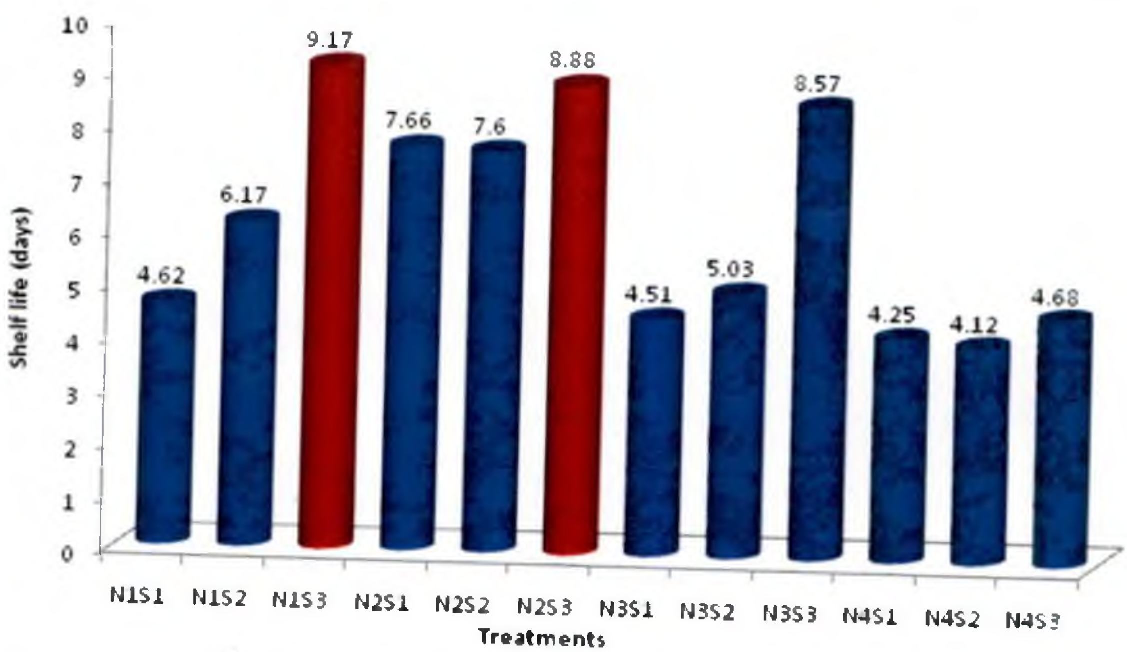

Fig 12. Treatment effect on shelf life in open air

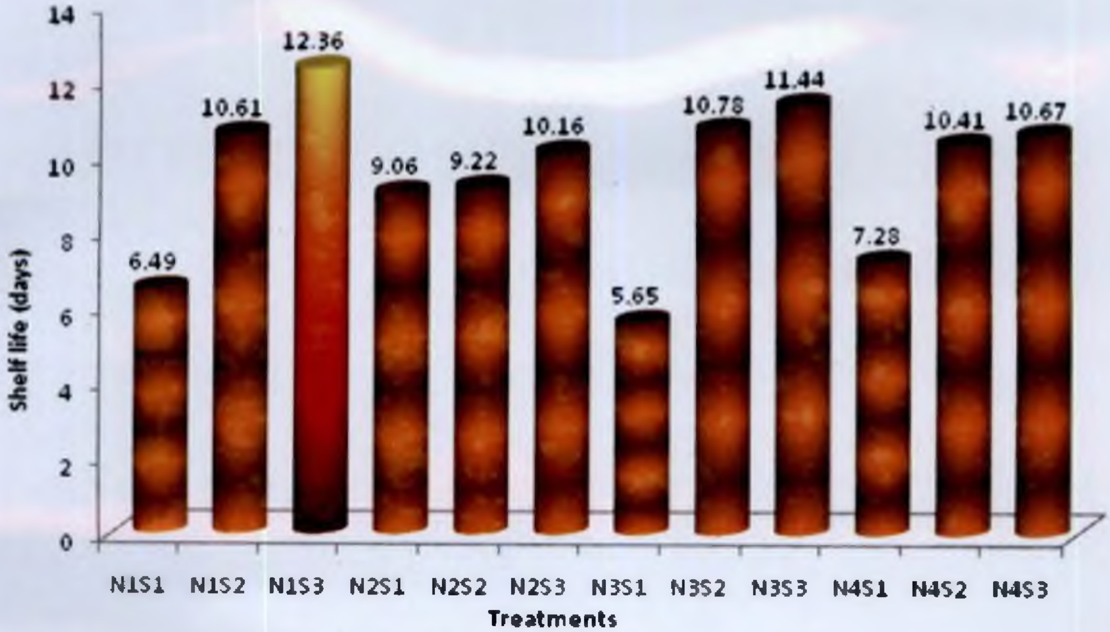

Fig 13.Treatment effect on shelf life in plastic cover

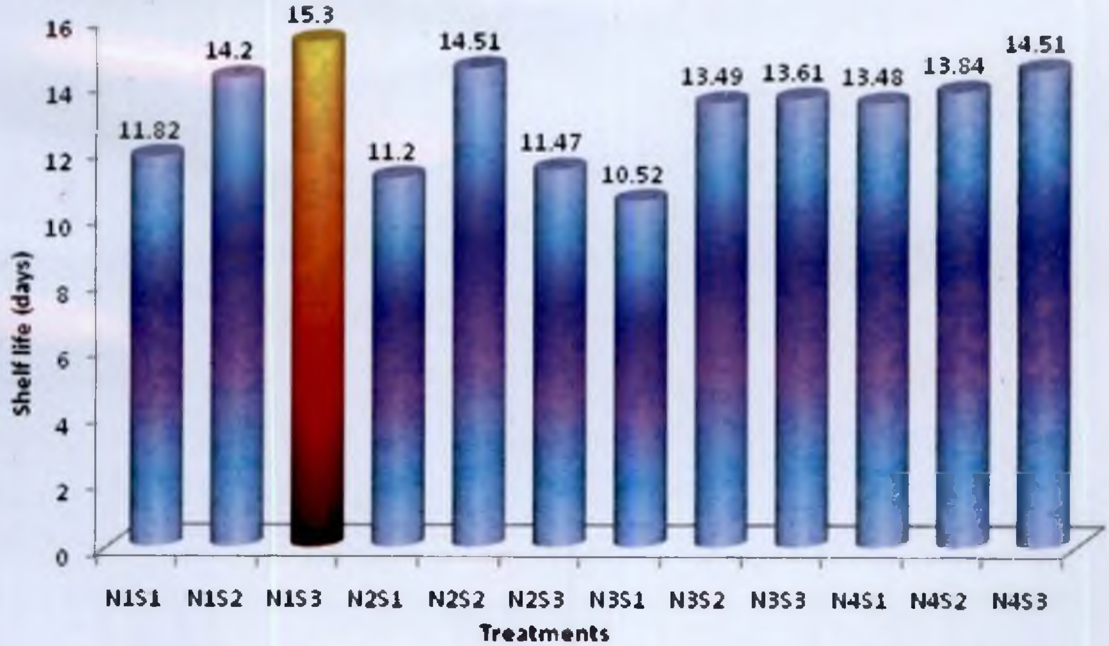

Fig 14. Treatment effect on shelf life in paper cover

vermicompost (25 t ha^{-1})] and were 6.91, 7.00 and 6.22 days respectively. Rodge and Yadlod (2009) also found out that the shelf life of tomato fruits was maximum for the treatment with 50% recommended fertilizer dose and 50% vermicompost.

5.1.4. Fruit quality studies

5.1.4.1. Vitamin C / Ascorbic acid

Vitamin C content is an important health conscious quality parameter for tomato fruits. The nutrient application alone had significant influence upon the vitamin C content. All the organic treatments overrode the POP recommended control implying that organic nutrition is superior over the chemical fertilizer treatment. Full organic nitrogen substitution recorded the highest vitamin C content and the lowest was recorded by POP recommendation (control).

Increase in vitamin C was reported in organically grown vegetables (beetroot, spinach, tomato, turnip, cabbage, lettuce, carrots, apples, pears) compared to conventionally cultivated crops by Salunkhe and Desai (1988); Heaton, (2001); Worthington, (2001); Asami et al., (2003); Lumpkin, (2005) and Uma Reddy et al., (2005). 'Tolstoi' tomato (*Lycopersicon esculentum*) when grown in organic nutrient solution of 100% and 50% vermicompost gave fruits with high vitamin C content than those obtained from plants grown in inorganic media (Shweta and Deepika, 2007).

It was found that application of organic nitrogen sources increased vitamin C content of tomato over no manure control (Prabakaran and Pitchai, 2002). Raut et al. (2003) reported high vitamin C content in fruits when farmyard manure plus *azospirillum* were applied together. Sable et al. (2007) observed more vitamin C content in treatments where 50% nitrogen through neem cake and 50% N through vermicompost as well as 25% N through neem cake and 75% N through vermicompost were given together. Thus the presence of vermicompost and neem cake supplements in the organic treatment could have also contributed to enhanced vitamin C content.

5.1.4.2. Total Soluble Solids (TSS)

The TSS content of fully red ripe fruits were observed to be slightly higher than that of the green matured ones. Helyes et al. (2006) reported that the brix degrees, carbohydrate and lycopene contents when measured in six ripeness stages from mature green to deep red stage, were the highest in the deep red stage.

Kumaran et al. (1998) found that quality parameters such as TSS, ascorbic acid and lycopene content were comparatively higher in organically grown tomato plants. Full organic nitrogen substitution recorded maximum TSS content for both the green mature ones and fully red ripe fruits followed by the POP recommendation. However 50% organic nitrogen substitution recorded a low content of total soluble solids for both mature green and fully ripe fruits. The presence of rockphosphate enriched vermicompost in presence of *azospirillum* and P solubilizer in the organic treatments could have raised the TSS content of fruits as reported by Patil and Madalageri (2003). Kannan et al. (2006) reported that application of vermicompost in combination with 2 kg *azospirillum* for tomato resulted in the highest total solids (5.4%).

Rodriguez et al. (2007) found out that addition of 50% vermicompost to the growth medium increased the soluble solids in tomato fruits. Pieper and Barrett (2009) in a study to determine whether the production system has a significant effect on the quality and nutritional content of one variety of processing tomatoes grown on a commercial scale, it was found that the total and soluble solids were significantly higher and consistency was greater in organic tomatoes. POP recommended plots with integrated supply of farmyard manure and chemical fertilizers recorded higher TSS content in fruits compared with the inferior organic treatments. Rodge and Yadlod (2009) found out that the TSS content in fruits was significantly more in case of integrated application of 50% recommended fertilizer dose plus 50% farmyard manure.

5.1.4.3. Lycopene

The deep red colour in ripe tomato is due to lycopene production. Helyes et al. (2006) reported that lycopene content changed significantly during maturation and accumulated mainly in the deep red stage. Full organic nitrogen substitution as well as the POP recommended plots recorded the highest lycopene content in fruits and the least was recorded by 50% organic nitrogen supplement. Potassium nutrition and uptake have a significant role in lycopene synthesis. Serio et al. (2007) reported that with increased potassium level, the lycopene content also increased linearly. Zdravkovic et al. (2007) also reported that the content of lycopene increased in plants treated with increased content of potassium. Potassium uptake was maximum for the organic treatments compared with POP recommended plots. But still, POP recommendation had a positive impact on lycopene synthesis inspite of its low potassium uptake. Rodriguez et al. (2007) found that addition of 50% vermicompost to the growth medium increased the K absorption.

Kumaran et al. (1998) reported that quality parameters such as lycopene were comparatively higher in organically grown tomato plants. Enriched vermicompost in presence of *azospirillum* would have raised the lycopene synthesis. It was reported that vermicompost application to tomato crop cultivated in kharif registered significantly higher lycopene content compared to other organically grown tomato (Sreedevi et al., 2005). Kannan et al. (2006) reported that application of 75% vermicompost in combination with 2 kg *azospirillum* for tomato resulted in high lycopene content (3.7 mg 100 g^{-1}). Lycopene content of conventionally cultivated tomato was found to be significantly lower.

Thus, it is concluded that when all the quality parameters of tomato are looked upon, the superior organic treatments with neem cake-trichoderma mass multiplied farmyard manure and rock phosphate enriched vermicompost (in presence of *azospirillum* and phosphate solubilizer) recorded maximum

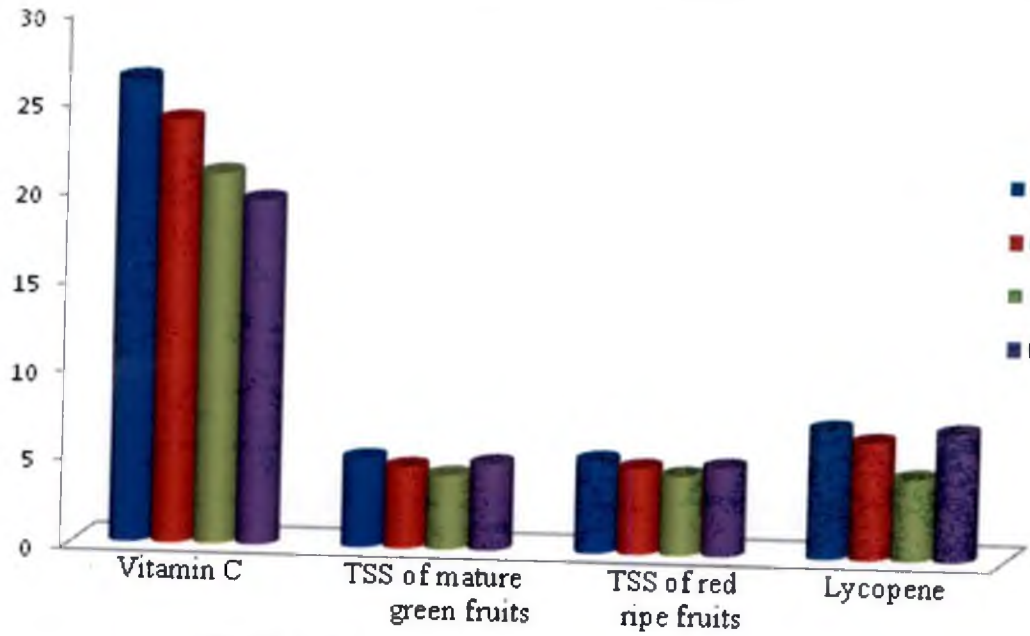

Fig 15. Effect of nutrient levels on quality parameters

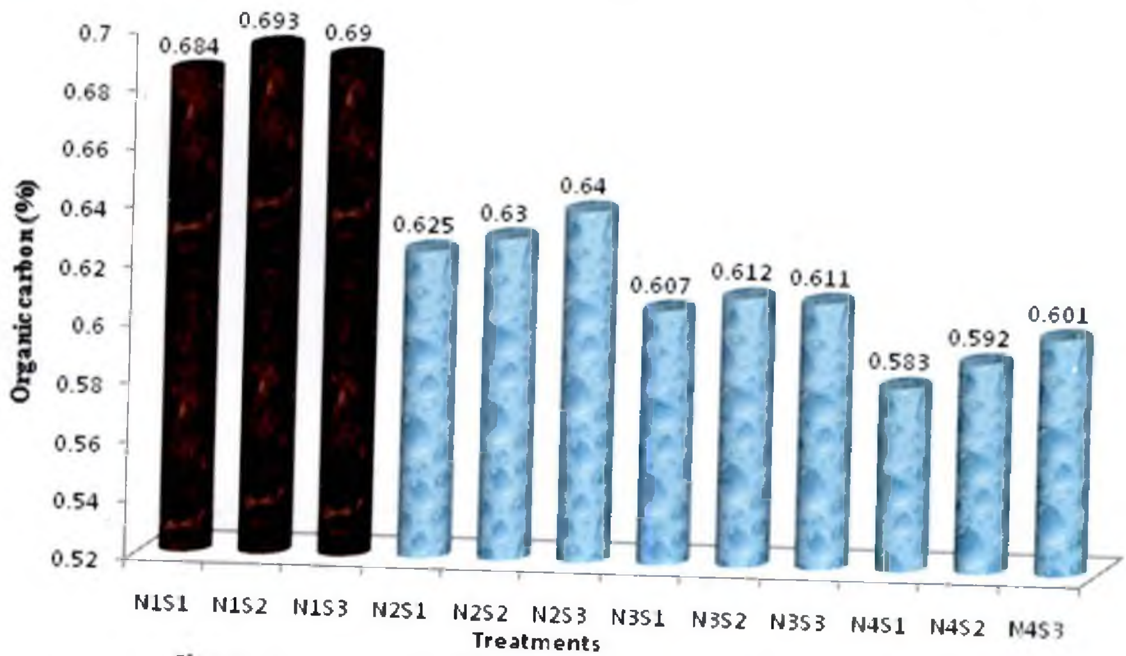

Fig 16. Treatment effect on organic carbon (%) in soil

improvement in fruit quality compared with the POP recommendation of integrated supply of farmyard manure and chemical fertilizers.

5.1.5. Benefit – Cost Ratio (B:C ratio)

The B:C ratio is closely related with the crop yield and prevailing market price of the crop produce. Organic tomato cultivation with full organic nitrogen substitution via farmyard manure (mass multiplied with neem cake and *trichoderma*) and rockphosphate enriched vermicompost (in presence of *a*zospirillum and phosphate solubilizer) in 1:1 proportion can be successfully recommended to the farmers, but only when premium prices are assured for their produce. It is proved from the experiment that POP recommendation recorded a high B: C ratio of 1.76 even at a normal price. Hence, if premium prices are not ensured, POP recommendation is the only means to get a better remuneration to the farmers from the crop. Raut et al. (2003) reported that the maximum net return with benefit: cost ratio of 2.30 was obtained when 100:50:50 kg NPK plus 20 tons farmyard manure were applied hectare^{-1}. Urea was added as a nitrogen source for the control plot in this experiment. Prabhakaran (2008) stressed the importance of urea to the soil which increased the net returns, gross returns and benefit- cost ratio of tomato cultivation.

The densely planted crops gave higher yields due to the increased number of plants unit area^{-1} and this was the reason for a high B:C ratio reflected from the closely spaced tomato plants, spaced at 60 cm x 30 cm. The wider spacings recorded low benefit-cost ratios corresponding to their low hectare^{-1} yields. The lowest B:C ratio was recorded by the widest spacing of 60 cm x 60 cm. Saglam et al. (1995) reported that wider spacing in tomato gave more fruits plant^{-1} than closer spacing, but the yield per unit area increased with closer spacing.

Thus, it could be concluded that POP recommendation along with a closer planting at 60 cm x 30 cm could economize the farmers' budget in tomato cultivation. This combination could record a high B:C ratio of 2.05 even at an off

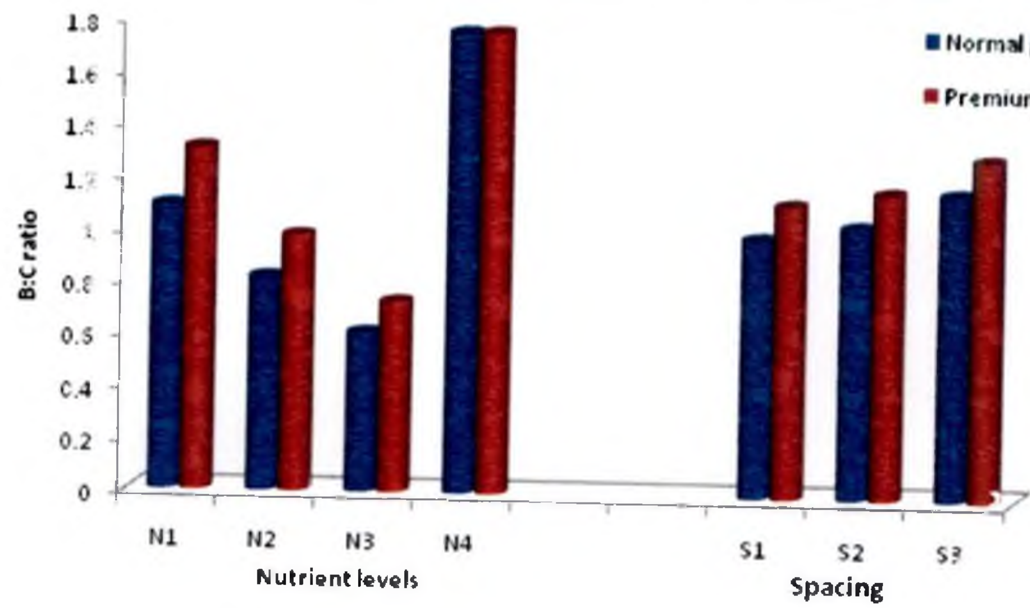

Fig 17. Effect of nutrient levels and spacing on B:C ratio

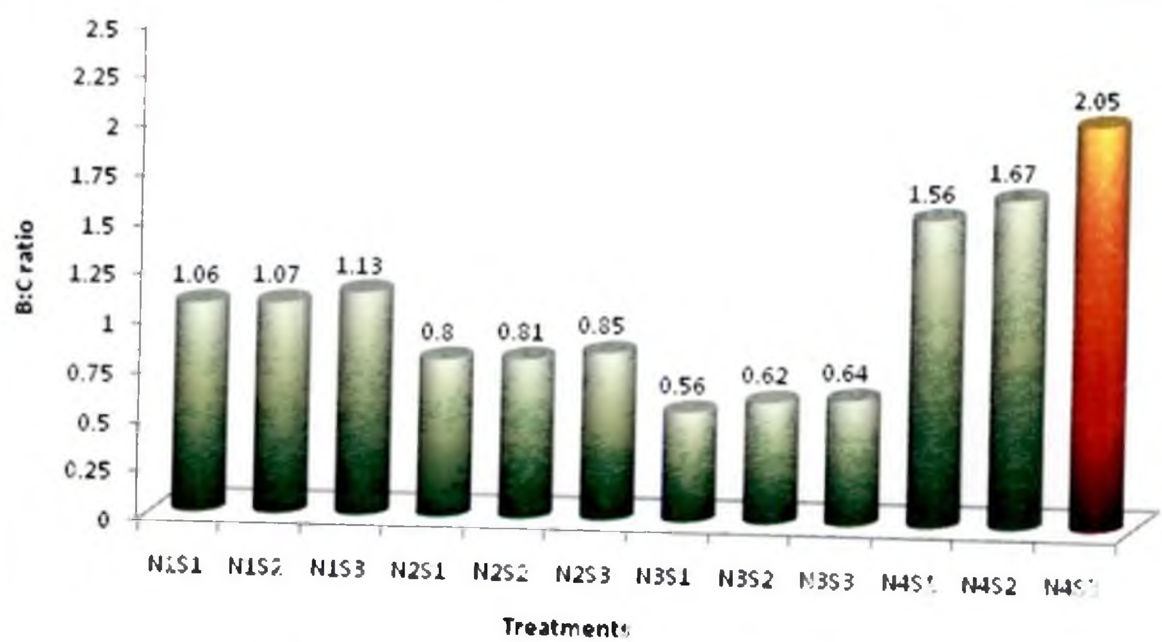

Fig 18. Treatment effect on B:C ratio at normal price

season cultivation. The economic returns from this crop would be again improved if it is raised at the proper time preferably in October. O[illegible] cultivation could be envisaged upon with full organic nitrogen substitution [illegible] manure and enriched vermicompost in 1:1 proportion combined with a close spacing of 50 cm x 30cm for better farm economics, provided that a premium price is assured for the produce. This combination also recorded a better B:C ratio of 1.36 and is farmer satisfactory.

5.1.6. Plant nutrient uptake

5.1.6.1 Nitrogen

The POP recommended treatment recorded maximum nitrogen uptake followed by full organic nitrogen substitution. The lowest uptake was recorded in 50 % organic nitrogen supply. The total uptake of nitrogen increased in tomatoes with the level of applied nitrogen according to Stark et al. (1983). Jose et al. (1988) reported that integrated use of urea and poultry manure resulted in a higher nutrient uptake. Fortunately, urea was the nitrogen source for POP recommended control plots.

Vermicompost has been demonstrated to be a valuable soil amendment that offer a balanced nutritional release pattern to plants, providing nutrients including available N, that can be taken up readily by plants (Edwards and Fletcher 1988;Edwards, 1998). Organic treatments consisted of *trichoderma* mass multiplied farmyard manure and rockphosphate enriched vermicompost (in presence of *azospirillum* and phosphate solubilizing bacteria) in 1:1 proportion. Utilization of organic nitrogen is an important aspect of plant nitrogen assimilation and has potential application in sustainable agriculture (Ge Ti da et al., 2008). Priya et al. (2008) reported that cowdung vermicompost was more supportive to the growth and multiplication of the nitrogen fixing *Azospirillum brasilense* and phosphate solubilizing *Pseudomonas maltophila*. In a field experiment conducted in Kerala to study the effects of enriched vermicompost on

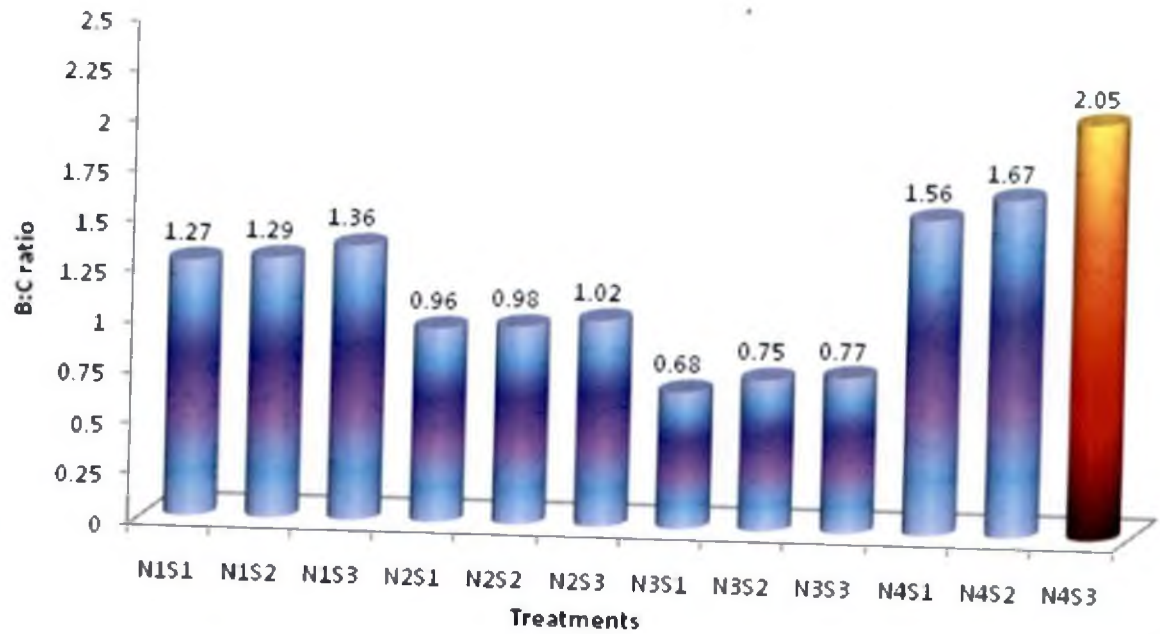

Fig 19. Treatment effect on B:C ratio at premium price

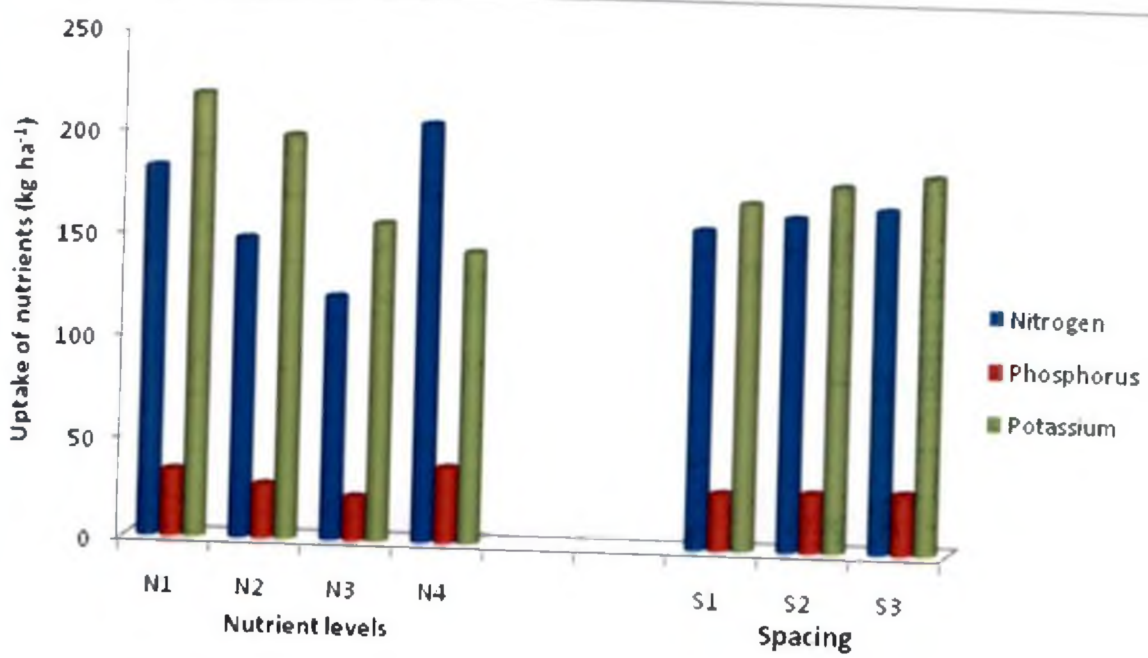

Fig 20. Effect of nutrient levels and spacing on uptake of nutrients

the yield and uptake of nutrients in cowpea, it was found out that enriched vermicompost was superior in terms of yield and uptake of major nutrients such as N, P, K, Ca and Mg (Kumari and Ushakumari, 2002).

The closely spaced plants recorded higher uptake values for nitrogen than the widely spaced ones. With increased plant density, the number of plants unit area^{-1} also increases resulting in higher nutrient uptake values unit area^{-1}.

5.1.6.2. Phosphorus

Very low levels of phosphorus in the substrate induce an increase in the rate of phosphorus uptake (Clarkson, 1981). This could be the reason for higher uptake under POP recommendation with integrated supply of farmyard manure and NPK. A similar trend as that of the nitrogen uptake had followed in case of plant phosphorus uptake also. Analyzing the N and K uptakes, the P uptake values were comparatively lower. Tomatoes absorb only small quantities of organic phosphorus according to Silva et al. (2009). The phosphorus uptake with organic treatments got upgraded because of the incorporation of rockphosphate enriched vermicompost. The POP recommended treatment recorded maximum uptake followed by full organic substitution and the lowest uptake was recorded in 50% organic substitution. The response to applied phosphate depends on the phosphorus status of the soil.

Worthington (2001) reported that phosphorus availability increases due to the solubilizing effect of organic acids, which are produced from decomposing organic manures. Further, the organic manures also reduce the fixation of phosphorus and increase the available phosphorus concentration in soil for absorption resulting in increased content of phosphorus in all vegetables. Rockphosphate enriched vermicompost was a component in the organic treatment. Enriching vermicompost with rockphosphate improved significantly the available P when inoculated with *Pseudomonas striata* which solubilized the added and native phosphate according to Vivek and Singh (2001). Phosphate solubilizing microorganism and vermicompost increased the availability of high-grade phosphate rock in soil according to Chandra et al. (2004). Patil and Madalageri (2003) in an experiment on green chilli revealed that a recommended dose of P_2O_5 (30 kg ha^{-1}) applied through rockphosphate along with P solubilizer, *Bacillus polymyxa* (*Paenibacillus polymyxa*) and vermicompost recorded the highest uptake in green chillies over treatments comprising of rockphosphate with or without *Bacillus polymyxa* or vermicompost

The closely spaced plants recorded higher uptake values than the widely spaced ones. With increased plant density, the number of plants unit $area^{-1}$ also increases resulting in higher nutrient uptake values unit $area^{-1}$.

5.1.6.3. Potassium

All organic substitutions recorded high potassium uptakes, however POP recommended control plot with integrated supply of farmyard manure and chemical fertilizers recorded minimum uptake. However, this observation is contradictory to the finding of Hannaway et al. (1980) who found that conventionally grown tomato registered significantly higher potassium content compared to organically grown vegetables. Maximum uptake was observed in full organic substitution. Perhaps, the presence of enriched vermicompost in the organic treatments would have enhanced the potassium uptake of plants. Similar reports of increased uptake were given by Kumari and Ushakumari (2002) in case of cowpea. Potassium is a particularly important nutrient for tomatoes (Diver, 2005). In a study it was reported that addition of 50% vermicompost to the growth medium increased K absorption (Rodriguez et al., 2007).

The closely spaced plants recorded higher uptake values than the widely spaced ones as in case of other nutrients.

5.1.7. Residual soil nutrient content

The residual soil nutrient content is a function of the initial nutrient content, quantum of added nutrients to soil and the plant nutrient uptake. Organic treatments significantly raised the organic carbon status of the soil. A major observation was that the residual soil nutrient status was maximum for the organic treatments and minimum for the POP recommended control. The finding is in accordance with the report of Sable et al. (2007) that nutrient uptake by tomato plants and the availability of nutrients in soil after harvest of the crop was more in treatments with organic source of nutrients through neem cake and vermicompost in variable combinations and alone. Neem cake was used for mass multiplying *trichoderma* with farmyard manure. The POP recommended control treatment added chemical fertilizers into the soil which had the least residual effect in soil. Makinde et al. (2010) reported that organic fertilizers had more residual effect than NPK fertilizers. Among the organic treatments, the residual nutrients in soil were in proportion to the quantum of added nutrients.

The initial organic carbon status in soil before the start of the experiment was low (0.574%). However the organic treatments had significantly raised the carbon status of soil. The residual carbon content was the highest in full organic nitrogen substitution followed by 75% organic nitrogen substitution. In a long term field experiment to examine the microbial biomass activity and nutrient availability, it was observed that microbial biomass and microbial activity were generally higher in organically than conventionally managed soils which increased the soil microbial biomass carbon and activity (Cong et al., 2006). Application of different organic amendments to soil favourably influenced the soil organic carbon, over the inorganics been applied alone (Kannan et al., 2005). Similar results were obtained by Stefaan et al. (2006). A review of all available comparative studies indicated that on an average, organic farming produces a minimum of 20% higher carbon level than that by inorganic farming (Gundula Azeez, 2009). Moreover several research studies revealed that organic farming sequesters adorable quantities of organic carbon to soil. Plant spacing did not significantly influence the soil organic carbon content.

The highest residual N was recorded in full organic nitrogen substitution followed by 75% substitution. Sable et al. (2007) reported that application of 25%

nitrogen through neem cake and 75% N through vermicompost together was more effective in increasing the nutritional value of soil after the harvest of tomato crop. The residual P_2O_5 and K_2O also followed the same trend as that of nitrogen.

5.2. Residual crop study – Amaranthus

Amaranthus was raised as a residual crop to study the residual nutrient effects in soil after the tomato crop.

5.2.1. Growth characters

Plant height, number of leaves and leaf area indices were determined at 40 DAS. The nutrient levels alone had significant influence upon plant height and number of leaves. But leaf area index was influenced by both treatment combinations and nutrient levels. Plant spacing did not have any significant effect upon these parameters. The plant height varied from 24.58 to 49.51 cm. The tallest plants were recorded in control (POP recommendation) plots and the shortest plants in 50% organic nitrogen substitution. Amaranthus is a crop highly responding to nitrogen application for its vegetative build up. Though the residual nitrogen content was low in POP recommended plots, still the ease of nitrogen availability would have increased the vegetative plant growth. The growth of amaranth is strongly influenced by soil fertility when this has been enhanced by an inorganic fertilizer according to Makus (1986). The number of leaves varied from 35.36 to 54.91. Both POP and full organic nitrogen substitution produced more leaves and the other organic nitrogen substitution produced less number of leaves. The POP recommendation with integrated application of farmyard manure and NPK fertilizers recorded the highest LAI while that with 50% organic nitrogen substitution recorded the lowest LAI. Alam et al. (2007) reported that integrated application of NPK and vermicompost resulted in enhanced vegetative growth of red amaranth. Malathi and Uma (2009) reported that vermicompost produced the best results over chemical fertilizer on the growth of amaranthus plants based on their physical parameters on the whole, probably due to the humic materials and other plant growth-influencing substances such as plant growth hormones produced by microorganisms during vermicomposting.

5.2.2. Uptake of nutrients

The experimental results revealed that the residual soil nutrient status was maximum for the organic treatments and minimum for the POP recommended control. Sharu (2000) observed high residual soil K in plots which received higher level of neem cake along with fertilizer. According to Sharma et al. (2009), in a cropping sequence of bhindi-onion, substantial improvement was recorded in residual soil fertility as the content of organic carbon, available nitrogen, phosphorus and potassium were significantly higher in case of plots which had received either farmyard manure or vermicompost in combination with chemical fertilizers than the plots which had received chemical fertilizers only.

Makinde et al. (2010) reported that organic fertilizers had more residual effect than NPK fertilizers. The residual nitrogen content varied from 197.59 to 257.7 kg ha^{-1}, residual phosphorous content varied from 85.52 to 123.01 kg ha^{-1} and the residual potassium content varied from 65.6 to 98 kg ha^{-1}in soil.

5.2.2.1. Nitrogen

The residual N uptake was proportional to the added quantum of nutrients into soil for raising tomato. POP recommended plots with integrated application of farmyard manure and chemical fertilizers viz. NPK recorded maximum residual nitrogen uptake by plants followed by that with full organic nitrogen substitution. The lowest uptake was recorded in 50% organic nitrogen substitution . Not only that, nutrients in organic manures are released gradually (Kumaraswamy, 2002), which might be advantageous in certain situations, but to meet the nutrient requirements of an extremely short duration C_4 crop such as amaranth, a judicious mix of organic and inorganic sources may be appropriate. Raj (2006) had reported that combined application of organic manures showed considerable residual effect in improving available nitrogen content of soil compared to the sole application of manures.

5.2.2.2. Phosphorus

The uptake was maximum in full organic nitrogen substitution and the least in 50% substitution. Phosphorus being relatively immobile in the soil remains near the site of fertilizer placement. It was generally admitted that recovery of applied phosphorus fertilizer by plants is very low as compared to other nutrients. Only 10-20 percent of applied fertilizer is available to the current crop and the rest is fixed in the soil by adsorption or precipitation (residual P) and is available for subsequent crops by adsorption and dissolution reactions (Wild, 1988).

5.2.2.3. Potassium

The control plots (POP recommendation) recorded the highest uptake followed by that with full organic nitrogen substitution and the lowest with 50% substistutiion.

5.2.3. Marketable yield of amaranthus

The control plot (POP recommendation) recorded the highest yield followed by that with full organic nitrogen substitution. The yield was the lowest in 50% organic nitrogen substitution. The observation was similar to that of the main crop tomato. This explains the ease of amaranthus plants to take up and assimilate the residual nutrients particularly from plots applied with chemical fertilizers. The growth and yield of amaranth is strongly influenced by soil fertility when this has been enhanced by an inorganic fertilizer and nitrogen supply is known to have a considerable effect on the yield of amaranth (Makus, 1986). A study conducted in grain amaranth by Kauffman and Weber (1990) revealed that there was no yield response to the added P and K which was probably due to the highest residual levels of P and K in the soil. Oliver et al.

(2001) conducted a study to evaluate the effect of organic and inorganic fertilizers on amaranthus and the best yield was reported in plots applied with inorganic fertilizer.

5.2.4. Benefit-Cost Ratio (B:C ratio)

The B:C ratio was the highest in control plots (POP recommendation) followed by full organic nitrogen substitution. 50% organic nitrogen substitution produced the lowest B:C ratio. Farmers could therefore be prompted to raise a residual amaranthus crop without any application of fertilizers or amendments after a tomato crop raised either with POP recommendation or raised organically with a supplement of cent per cent N through farmyard manure (mass multiplied with *trichoderma* and neem cake) and rockphosphate enriched vermicompost (in presence of *azospirillum* and phosphate solubilizer) in 1:1 proportion, to get an economical produce.

5.3. Combined B:C Ratio

5.3.1. At normal market price

The economics of tomato and amaranthus crops were combined in order to get a pooled or combined B:C ratio which determines the actual economic mind build up of farmers for raising the two crops. Farmers could be easily encouraged to raise the second crop of amaranthus as it didn't require much input other than seeds and irrigation water mainly. However, the combined B:C ratio determines its feasibility. Quantity of applied nutrients to soil influenced the combined B:C ratio positively. The POP recommendation (control) gave the highest combined B:C ratio of 1.80 followed by full organic nitrogen substitution (1.21). The B:C ratio was the lowest in 50% organic nitrogen substitution and was 0.69. Raut et al. (2003) reported that in tomato the maximum net return with benefit: cost ratio of 2.30 was obtained when 100:50:50 kg NPK plus 20 tons farmyard manure hectare^{-1} were applied. Prabhakaran (2008) observed that application of organic nitrogen in the form of 150 kg N as urea to the soil increased the net returns, gross returns and benefit- cost ratio of tomato cultivation to 5.2.

Closer planting gave higher benefit-cost ratio compared to wider planting. In case of plant spacing, densely planted crops gave higher yields due to the increased number of plants unit area^{-1}. This was the reason for a high B:C ratio reflected from the closely spaced plants. The wider spacing recorded low benefit-cost ratios corresponding to their low hectare^{-1} yields. Hence, organic farming of tomato-amaranthus couldn't be feasible with the prevailing market price of tomato and farmers' economy could be improved if POP cultivation of tomato followed by raising residual crop amaranthus without extra inputs.

5.3.2. Premium price

Organic tomatoes could be registered with a premium price slightly higher than the normal market price. Hence, premium prices were determined for organic tomatoes with 20% hike over the normal market price which had been already discussed in a previous session. Attaching premium price for organic tomato could not however raise the combined B:C ratio beyond that recorded by POP recommended control. But, the margin of disparity between the two could be reduced and hence the trend of variation was similar to that of combined B:C ratio at normal market price.

POP recommendation (control) gave the highest combined B:C ratio (at premium price) of 1.79 followed by full organic nitrogen substitution with B:C ratio of 1.38. The B:C ratio was the lowest in 50% organic nitrogen substitution (0.78). Closely planted gave the highest B:C ratio of 1.30.

Though a premium price was imparted to organic tomatoes, it couldn't raise the B:C ratio for the two crops viz., tomato and amaranthus up to a farmer satisfactory level. However, the combination of full organic nitrogen substitution with close plant spacing of 60 cm x 30 cm recorded a fair B:C ratio of 1.42 which could be considered farmer satisfactory. But this is much less compared to a near

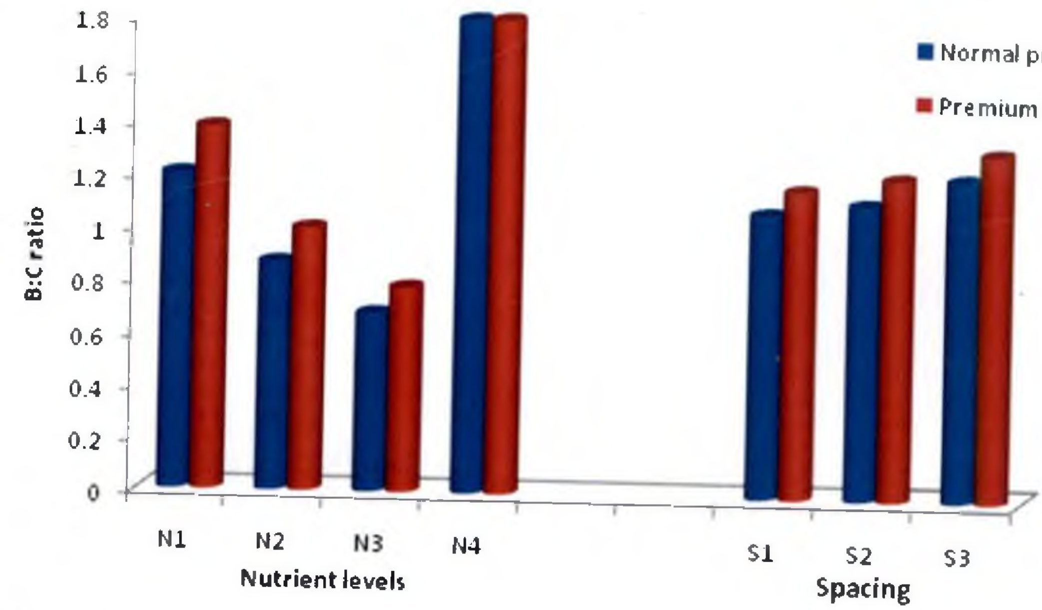

Fig 21. Effect of nutrient levels and spacing on economics of tomato-amaranthus sequence

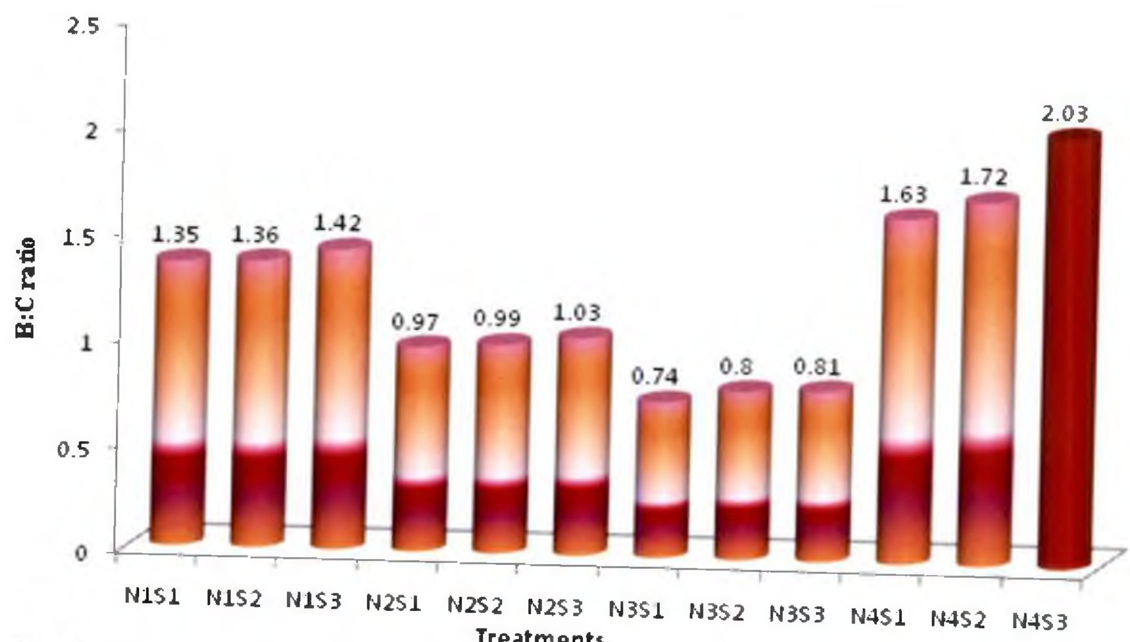

Fig 22. Treatment effect on B:C ratio of tomato-amaranthus sequence at premium price

double output from the POP recommended control clubbed with 60 cm x 30 cm spacing with B:C ratio of 2.03. Organic cultivation can raise only the qualitative aspects of the crop and not the quantitative aspects. Hence, with respect to the combined yield and B:C ratio of both tomato and the residual crop amaranthus, POP recommendation clubbed with close spacing of tomatoes at 60 cm x 30 cm fetches the best economy from farmers' point of view. Raising tomatoes followed by residual amaranthus with a combination of full organic nitrogen substitution via farmyard manure and enriched vermicompost in 1:1 proportion with 60 cm x 30 cm tomato plant spacing shall also be fairly economical to the farmer, provided, a premium price is assured for the organic tomato produce.

SUMMARY

6. SUMMARY

A field experiment was conducted at the Instructional Farm attached to the College of Agriculture, Vellayani during 2009-2010 to study the effects of organic nutrition and spacing and their interaction upon growth, yield, quality and nutrient uptake of tomato and to assess the residual effect of organic nutrition on the succeeding crop.

The total experimental area comprised of 5.8 cents with a total number of 36 plots and each plot area was 4.32 m^2. The nutrient levels were scheduled as N_1 (Full recommended dose of N as organic and as FYM and enriched vermicompost in 1:1 proportion), N_2 (75 % recommended dose of N only and as organic as FYM and enriched vermicompost in 1:1 proportion), N_3 (50 % recommended dose of N only and as organic as FYM and enriched vermicompost in 1:1 proportion) and N_4 as control (Package of Practices Recommendations 'Crops': 2007 of Kerala Agricultural University – FYM -25 t ha^{-1} + NPK @ 75:40:25 kg ha^{-1}). Plant spacing was also given special importance like that of nutrition and spacing tried were 60 cm x 60 cm, 60 cm x 45 cm and 60 cm x 30 cm respectively. Common treatments such as neem seed oil garlic emulsion spray, pseudomonas seed pelleting and seedling sprays, trichoderma incorporation in farmyard manure, uniform mulching and uniform irrigation at appropriate intervals were also carried out.

The crop was ready for the first harvest at 90 to 100 days after sowing (DAS) which varied with the treatments. Biometric observations such as plant height, number of leaves, leaf area index and number of branches were taken from randomly selected observation plants throughout the growth stages at time intervals and dry matter production after harvesting the produce. Other observations including flowering, fruiting, fruit characters, quality characters and shelf life of fruits were also taken and the salient findings of the experiment are summarized here.

The tallest plants with the highest number of leaves and LAI were found in N_4 followed by N_1 and the shortest plants with the lowest number of leaves and LAI were found in N_3 throughout the growth stages. The widest spaced plants produced the tallest plants with more leaves and the closely spaced the shortest with less number of leaves. Like height and number of leaves, the branching was also found the highest in N_4 and widely spaced plants.

Early flowering was observed in N_3 (47 days) and delayed flowering in N_2 (51.22 days). Delayed flowering was observed in the wider (51.75 days) and the widest spaced plants (49.92 days) compared to the closely spaced plants (47 days). The number of flowering bunches plant^{-1} was found the highest in N_1 (5.78). Also the closely spaced plants recorded the highest flowering bunches plant^{-1} (6.42).

The fruit yield and fruit weight were the highest in N_4 (557.47 g plant^{-1} and 25.88 g respectively) and were the lowest in N_3 (214.89 g plant^{-1} and 18.69 g respectively). The widest spaced plants produced the heaviest fruits (22.72 g) with the highest fruit yield (425.54 g plant^{-1}) and the combination of N_4 and S_1 itself (N_4S_1) recorded the highest yield with the heaviest fruits (663.19g plant^{-1} and 28.1 g respectively).

Among the three different storage methods, paper cover storage was found the best with N_4 recording a storage period of 13.94 days followed by N_1 (13.77 days), N_3 (12.54 days) and N_2 (12.39 days) respectively.

In open air storage, the longest shelf life was in N_2 (8.05 days) while in 30 micron plastic cover it was in N_1 (9.82 days) and in paper cover it was in N_4 (13.94 days). The shelf life of fruits was the longest in closely spaced (S_3) plants in both open air and 30 micron plastic cover storage (11.16 days each respectively) and in widely spaced (S_2) plants in paper cover storage (14.01 days). The interaction effects were significant with the longest shelf life in N_1S_3 in all the three storage methods studied such as open air, 30 micron plastic cover and paper cover (9.17, 12.36 and 15.30 days respectively).

Red coloured tastier fruits with the highest vitamin C and lycopene content were produced by N_1 (26.18 and 7.33 mg 100 g^{-1} fruit respectively) and plumpy fruits by N_4 (12.92 cm). Though the effect of spacing was not significant in any of the quality characters, the interaction effect was significant with respect to lycopene and TSS content with N_1S_1 giving the highest values for them (8.69 mg 100 g^{-1} fruit and 5.13 ^0B respectively).

The fruit cracking percentage was the lowest in N_4 (2.32%) and the fruit borer infestation, the lowest in N_2 (2.64%). The wider spaced (S_2) plants recorded the lowest fruit cracking percentage (3.76%) and the widest spaced (S_1), the lowest fruit borer infestation (1.37%). The interaction effects were significant in fruit borer infestation and Tomato Yellow Leaf Curl Virus (TYLCV) infection with N_1S_3 recording the highest percentage for both (16.68% and 28.27% respectively).

The effect of nutrient levels and spacing were significant in B:C ratio at the normal market price of the produce and was the highest in N_4 (1.76) and closely spaced plants (1.17). At the premium price of the produce, the B:C ratio was the highest in N_1 (1.31). The interaction effects were also significant with the highest B:C ratio in N_4S_3 (2.05) at the normal market price and at the premium price it was in N_1S_3 (1.36) the highest B:C ratio recorded among the organic treatments.

The dry weight of the plant was the highest in N_1 (82.13 g $plant^{-1}$) and in the widest spacing (94.99 g $plant^{-1}$) and the treatment combination of N_1 and S_1 (N_1S_1) itself produced the highest dry weight (103.93 g $plant^{-1}$).

The uptake of nutrients was significantly influenced by the nutrient levels and spacing. Nitrogen and phosphorus uptake was found the highest in N_4 (157.62 kg ha^{-1} and 15.3 kg ha^{-1} respectively) and potassium, the highest in N_1 (60.99 kg ha^{-1}). The nutrient uptake was the highest in closely spaced (S_3) plants (15.9 kg ha^{-1} P_2O_5 and 59.64 kg ha^{-1} K_2O respectively).

The organic carbon and available nutrient content of the soil after the experiment was found the highest in N_1 (0.689%). The interaction effect was significant in organic carbon content alone with the highest in N_1S_2 (0.693%) and the lowest in N_4S_1 (0.583%).

In order to study the residual effect of organic nutrition, amaranthus (*Amaranthus tricolor*) was raised after tomato in the same field.

The effect of nutrient levels was significant in all the biometric characters studied such as plant height, number of leaves and LAI and was the highest in N_4 and the lowest in N_3. The interaction effect was found significant for LAI only with the highest in N_4S_1 (2.222) and lowest in N_3S_1 (1.532).

The effect of nutrient levels was significant in marketable yield of amaranthus and was the highest in N_4 (25.16 t ha^{-1}) and the lowest in N_3 (12.83 t ha^{-1}). The economics of amaranthus cropping after tomato revealed the significance of nutrient levels, spacing and their combination on the B:C ratio of amaranthus at the normal market price of the produce. The B:C ratio was found the highest in N_4 (1.94) and in closer spacing of plants (S_3) (1.43) and the lowest in N_3 (0.99) and in wider spacing of plants (S_1) (1.40). The combination of N_4S_3 (1.96) recorded the highest B:C ratio and N_3S_1, the lowest (0.99).

The uptake of nutrients was significantly influenced by nutrient levels with the highest uptake of N and K in N_4 and the lowest in N_3. The uptake of P was the highest in N_1 (19.19 kg ha^{-1}) and the lowest in N_3 (13.34 kg ha^{-1}). The interaction effect was significant with the highest uptake in N_4S_3 and the lowest in N_3S_1. The effect of plant spacing was not significant.

The combined B:C ratio of tomato and amaranthus sequence was determined at the premium price of tomato plus the market price of amaranthus by assuming a 20 % hike for the organic produce in the market. The effect of nutrient levels and spacing were significant with N_4 giving the highest B:C ratio (1.79) and N_3, the lowest (0.78). The closely spaced plants (S_3) recorded the highest B:C ratio (1.32) and the widest spaced plants (S_1) the lowest (1.17). The interaction effect was significant with the highest B:C ratio in N_4S_3 (2.03) and the lowest in N_3S_1 (0.74).

From the study it could be concluded that tomato can be produced organically with a B:C ratio of 1.31 by applying nitrogen @ 200 kg ha^{-1} as FYM and enriched vermicompost in 1:1 proportion. By organic cultivation the quality parameters such as vitamin C, Total Soluble Solids and lycopene content were increased and taste and colour became preferential. Organic nutrition enhanced the storage period in open air and 30 micron plastic cover while paper cover storage was found the most suitable for integrated nutrient application (POP). However the paper cover storage was found the best for all treatments including nutrient levels, sources and spacing. Thus from the food and environmental safety point of view, organic production can be recommended where in the B:C ratio also didn't go below one. With respect to pest and disease incidence it was the spacing more important than the source of nutrients as closer spacing is favourable for the build up of pests and diseases than wider spacing. When we look into the economics of tomato production, the closely spaced plants produced much higher $hectare^{-1}$ yield, while the widely spaced the highest $plant^{-1}$ yield because of the higher and lower plant population in the closely and widely spaced plants. So the present study envisages further studies as detailed below in future programmes.

Future line of work

- More studies to be conducted for fixing the optimum quantity of nutrients through organic fertilization.
- Other organic sources also should be evaluated.
- Organic plant protection measures to be studied in a scientific way.
- Varietal variation in responding to organic sources should also be studied.
- Population effect on pests and diseases incidence should also be studied.

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APPENDICES

APPENDIX – I

Weather data for the cropping period

(November 2009 to April 2010)

Standard week	Temperature (^0C)		Rainfall (mm)	Relative humidity (%)	Evaporation (mm day^{-1})
	Minimum	Maximum			
45	23.5	29.3	408.0	80.9	2.7
46	23.9	30.8	187.0	80.9	2.9
47	23.5	29.2	73.0	84.9	2.9
48	23.5	28.4	0.0	85.4	3.2
49	23.6	29.4	63.0	88.9	3.1
50	23.5	30.6	74.0	82.6	3.3
51	23.9	30.9	0.0	85.4	3.4
52	23.7	30.8	0.0	86.9	3.5
1	23.2	31.1	6.0	85.0	3.6
2	22.9	30.9	36.0	85.1	3.3
3	23.2	31.3	0.0	85.0	3.4
4	22.9	31.5	0.0	79.7	3.5
5	23.7	31.6	0.0	82.4	3.6
6	24.3	31.7	0.0	80.6	3.6
7	23.7	31.9	0.0	79.4	3.8
8	23.9	32.6	0.0	77.0	3.9
9	24.2	33.5	0.0	73.9	4.0
10	24.3	33.7	0.0	73.5	4.3
11	24.5	33.8	0.0	89.3	4.3
12	24.4	33.9	0.0	89.1	4.5
13	24.5	33.6	0.0	88.3	4.7
14	25.0	34.1	13.0	89.7	4.7
15	25.6	34.8	0.0	84.6	4.8
16	25.8	34.5	33.0	85.0	4.5

APPENDIX – II

Cost of cultivation of tomato

1. Cost of inputs

Sl No.	Inputs	Unit cost (Rs)
1	Seeds	2214 kg^{-1}
2	Trichoderma	70 kg^{-1}
3	Neem seed oil	80 kg^{-1}
4	Pseudomonas	80 kg^{-1}
5	FYM	0.25 kg^{-1}
6	Enriched vermicompost	6 kg^{-1}
7	Neem cake	12 kg^{-1}
8	Urea	5 kg^{-1}
9	Mussourie phos	6 kg^{-1}
10	MOP	5 kg^{-1}
11	Labour	290 day^{-1}

2. Cost of cultivation ha^{-1} for N_1

Sl No.	Inputs	Quantity ha^{-1}	Cost ha^{-1} (Rs)
1	Seeds	450 g	996
2	Trichoderma	29 kg	2030
3	Neem seed oil	66 kg	5280
4	Pseudomonas	5 kg	400
5	Neem cake	2500 kg	30000
6	FYM	25000 kg	6250
7	Enriched vermicompost	5100 kg	30600
8	Labour	130 days	37700
9	Total cost	-	113256

3. Cost of cultivation ha^{-1} for N_2

Sl No.	Inputs	Quantity ha^{-1}	Cost ha^{-1} (Rs)
1	Seeds	450 g	996
2	Trichoderma	25 kg	1750
3	Neem seed oil	66 kg	5280
4	Pseudomonas	5 kg	400
5	Neem cake	1870 kg	22440
6	FYM	18700 kg	4675
7	Enriched vermicompost	3800 kg	22800
8	Labour	130 days	37700
9	Total cost	-	96041

4. Cost of cultivation ha^{-1} for N_3

Sl No.	Inputs	Quantity ha^{-1}	Cost ha^{-1} (Rs)
1	Seeds	450 g	996
2	Trichoderma	21 kg	1470
3	Neem seed oil	66 kg	5280
4	Pseudomonas	5 kg	400
5	Neem cake	1250 kg	15000
6	FYM	12500 kg	3125
7	Enriched vermicompost	2600 kg	15600
8	Labour	130 days	37700
9	Total cost	-	79571

5. Cost of cultivation ha^{-1} for N_4

Sl No.	Inputs	Quantity ha^{-1}	Cost ha^{-1} (Rs)
1	Seeds	450 g	996
2	Trichoderma	29 kg	2030
3	Neem seed oil	66 kg	5280
4	Pseudomonas	5 kg	400
5	Neem cake	2500 kg	30000
6	FYM	25000 kg	6250
7	Urea	161 kg	805
8	Mussoorie phos	189 kg	1134
9	MOP	42 kg	210
10	Labour	130 days	37700
11	Total cost	-	84805

PRODUCTION PROTOCOL FOR ORGANIC TOMATO

(*Lycopersicon esculentum* Mill.)

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Abstract of the thesis submitted in partial fulfillment of the requirement
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ABSTRACT

The research project entitled 'Production protocol for organic tomato (*Lycopersicon esculentum* Mill.)' was conducted at the Instructional Farm attached to the College of Agriculture, Vellayani during the year 2009-2010 to study the effects of organic nutrition and spacing and their interaction upon growth, yield, quality and nutrient uptake of tomato and to assess the residual effect of organic nutrition on the succeeding crop. The experiment was laid out in factorial randomized block design (RBD) with three replications. The treatments consisted of four levels of nutrients, N_1 (full nitrogen substitution as organic), N_2 (75% nitrogen only and as organic), N_3 (50% nitrogen only and as organic) and N_4 (Package of Practices Recommendations 'Crops': 2007 of Kerala Agricultural University) and three spacing viz., S_1 (60 cm x 60 cm), S_2 (60 cm x 45 cm) and S_3 (60 cm x 30 cm).

Before transplanting, the seedlings were given a root dip in *Pseudomonas flourescens* culture against bacterial wilt disease. The experiment was laid out as 4 x 3 factorial randomized block design (FRBD) with 3 replications. The number of treatments were 12 replication^{-1}. Common treatments such as neem seed oil-garlic emulsion spray, pseudomonas spraying, trichoderma incorporation in the soil and uniform mulching at different intervals were also undertaken.

From the results it was found that integrated supply of nutrients through FYM and chemical fertilizers gave the highest fruit yield in tomato. Among the different spacing, the widest spacing of 60 cm x 60 cm recorded the highest fruit yield plant^{-1}. The interaction effects were significant with the highest yield in the combination where the individual effects of nutrient levels as well as spacing were significantly the highest, viz., N_4S_1. The fruit weight was also the highest in the same treatments and the crop duration the modest. The lowest fruit weight and the shortest duration of crop was observed in N_3. The widest spaced plants produced the highest fruit weight and the combination involving POP recommendation and the widest spacing (N_4S_1) again produced the heaviest fruits.

The fruit quality and appearance was also found the best in N_1 and N_4 when compared to other two levels. Spacing had no effect on the quality characters while the interaction between nutrient levels and spacing had significant effect on lycopene and TSS content with N_1S_1 giving the highest values for them.

The dry weight of plants was found the highest in N_1 and in the widest spacing (S_1) and among the interaction the same combination produced the highest plant dry weight (N_1S_1).

The nutrient uptake especially N and P was found the highest in N_4 and K in N_1. In closer planting the nutrient uptake was the highest consequent to the increase in population.

The organic carbon and available nutrient status after the experiment was the highest in N_1.

The effect of nutrient levels and spacing were significant in benefit-cost ratio at the normal market price as well as the premium prices of the produce. The POP recommendation (N_4) with an integrated nutrient approach with organic and inorganic sources fetched the highest B:C ratio. Similarly for planting distances, it was found that tomato cultivation become remunerative in terms of B:C ratio only when the plants were spaced at a closer distance than wider spacing.

Inorder to study the residual effect of organic nutrition, a crop of amaranthus (*Amaranthus tricolor*) was raised after tomato and the biometric characters of the residual crop studied were influenced by nutrient levels with the highest values in N_4 (control) and the lowest in N_3. The marketable yield of amaranthus was also found the highest in N_4 (control). Similarly the economics of amaranthus cultivation revealed the significance of N_4 and S_3 in producing the highest B:C ratio. The combination of N_4 and S_3 also recorded the highest B:C ratio in amaranthus.

The uptake of nutrients especially N and K was found the highest in N_4 and N_1. Though spacing had no significant role in the uptake of nutrients, the combination of nutrient levels and spacing had significant influence and the highest uptake was observed in N_4S_3.

The combined B:C ratio of tomato-amaranthus sequence was determined at the premium price of tomato plus the market price of amaranthus by assuming a 20 % hike for the organic produce in the market. The effect of nutrient levels and spacing were significant with N_4 giving the highest B:C ratio and N_3 the lowest. The closely spaced plants (S_3) recorded the highest B:C ratio and the widest spaced plants (S_1), the lowest. The interaction effect was significant with the highest B:C ratio in N_4S_3 and the lowest in N_3S_1. Among the organic treatments N_1 was found the best with a combined B:C ratio of 1.38 followed by N_2 (1.00) and the lowest in N_3 (0.78). Among the organic combination with spacing it was in N_1S_3 the highest B:C ratio found (1.42) followed by N_1S_2 (1.36) and N_1S_1 (1.35).